PB-214 113

EVALUATION OF CANAL LINING FOR SALINITY CONTROL IN GRAND VALLEY

Gaylord V. Skogerboe, et al

Robert S. Kerr Water Research Center
Ada, Oklahoma

October 1972

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W 73-03518

EPA-R2-72-047
October 1972

EP 1.23/2:72-047

PB 214 113

Environmental Protection Technology Series

Evaluation of Canal Lining for Salinity Control in Grand Valley

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INPUT TRANSACTION FORM

1. Report No. 2.

W 73-03518

EVALUATION OF CANAL LINING FOR SALINITY CONTROL IN GRAND VALLEY,

5. Report Date

8. Performing Organization Report No.

Skogerboe, G. V., and Walker, W. R.

→ EPA Project

13030DOA

14-01-201

Type of Report and Period Covered

Agricultural Engineering Department,
Colorado State University,
Fort Collins, ~~Colorado~~

12. Sponsoring Organization ~~EPA, Office of Research and Monitoring~~

Environmental Protection Agency report
~~number~~ EPA-R2-72-047, October 1972. 199 p, 59 fig, 36 tab, 39 ref

Introduction of seepage and deep percolation losses to the saline soils and aquifers, and the eventual return of these flows to the Colorado River with their large salt loads, make the Grand Valley in Colorado one of the more significant salinity sources in the Upper Colorado River Basin. The Grand Valley Salinity Control Demonstration Project was designed to evaluate the salinity control effectiveness of canal and lateral linings for reduction of seepage losses into the ground water.

A detailed evaluation of the necessary hydrologic and salinity parameters in the principal demonstration area was made. A hydro-salinity model has been prepared, which has allowed the itemizing of the various segments of the dual flow system into water and salt budgets for the periods prior to and immediately after the construction of the linings. In addition, the results of this study and others conducted previously were employed to derive some generalized valley-wide water and salt budgets. The salinity control benefits to the Lower Basin exceeded the costs of the canal lining program. (EPA abstract)

*Colorado River, Irrigation, *Irrigation Canals, Irrigation Effects, Irrigation Efficiency, Irrigation Water, *Return flow, Saline soils, Saline water, Salinity, Seepage, Water distribution (Applied), Water loss, Water pollution sources, Water quality, *Canal linings

*Grand Valley (Colo), *Salinity control.

72-047

Copy available from GPO Sup Doc as EP 1.23/2:, $2.75; microfiche from NTIS as PB 2[illegible], $0.95.

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19. Security Class (Report)

20. Security Class (Page)

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EPA-R2-72-047
October 1972

EVALUATION OF CANAL LINING FOR SALINITY CONTROL IN GRAND VALLEY

By

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Contract No. 14-01-201
Project 13030 DOA

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Prepared for

OFFICE OF RESEARCH AND MONITORING
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

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For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $2.75

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ABSTRACT

Introduction of seepage and deep percolation losses to the saline soils and aquifers, and the eventual return of these flows to the river system with their large salt loads, make the Grand Valley in Colorado one of the more significant salinity sources in the Upper Colorado River Basin. The Grand Valley Salinity Control Demonstration Project was designed to evaluate the salinity control effectiveness of canal and lateral linings for reduction of seepage losses into the ground water.

In order to meet the specific objectives of this study, a detailed evaluation of the necessary hydrologic and salinity parameters in the principal demonstration area was made. A hydro-salinity model has been prepared, which has allowed the itemizing of the various segments of the dual flow system into water and salt budgets for the periods prior to and immediately after the construction of the linings. In addition, the results of this study and others conducted previously were employed to derive some generalized valley-wide water and salt budgets.

Conclusions and recommendations formulated during the course of the study, which were deemed pertinent in the study area, were extended to a valley wide context. Suggestions made have been based upon the results obtained in this study concerning areas of needed research for more effective future salinity control, institutional constraints which must be examined for efficient salinity management, and improvements to the existing agricultural system in Grand Valley that will reduce salt loadings to the Colorado River from the valley.

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SECTION I

CONCLUSIONS

The basis for reducing salt loadings entering the Colorado River as it passes through the Grand Valley is to minimize the water which is percolating through the soil profile and into the ground water basin. At the present level of salinity control technology, it is difficult to determine what effect a 50% reduction in these flows would have. It may vary between 30 and 70% in the corresponding reduction of salt loadings. However, the bulk of the deep percolation losses are the result of excessive irrigation applications and, as such, the objective of any salinity control alternative should include measures to improve the efficiency of on-farm water management.

The first and most important consideration in improving farm water use is control. Implied in this realization is the requirement of sound water measurement at the farm turnout and again at critical division points among farmers below the turnout. This would necessitate a considerable rehabilitation of both the canal and lateral system, and the implementation of a "call period" to allow canal operators more time for flexible water handling. In addition, it is an important requirement that the canal companies extend their control of the water below the canal turnout structure to include key division points within the lateral system to insure equitable allocation of water among users.

Another important farm water management tool that must eventually be considered is an irrigation scheduling program. By simply applying the proper quantity of water at the correct time, a significant reduction in deep percolation losses can be achieved. In this type of program, the emphasis is not only on improving crop production by more efficient use of water and fertilizer, but also on salinity management which is an added dimension to the program.

Drainage in the Grand Valley is generally ineffective in at least 30% of the lower lying areas where water table problems become compounded by subsurface inflows from the higher lands. It has been established that the vast majority of subsurface return flows occur in a highly permeable cobble and sand strata resting upon the Mancos shale formation. As a result, the possibility of employing drainage as a salinity control program seems feasible since it would reduce the detention time the water has contact with the highly saline soils, aquifer, and Mancos shale. Drainage schemes including field tile drainage, interceptor drainage, and drainage by pumping seem to be the most realistic methods.

It should be emphasized as an important conclusion of this study that no single salinity control measure will effectively alleviate the Grand Valley salinity problem. It is thus essential that an integrated program of a planned combination of these schemes be implemented for efficient salinity control.

Probably the most binding constraint for reducing salinity from the valley is not in the feasibility of the alternatives mentioned above, but in the institutional structure of western water laws. In order for water management in the area to improve without devastation of the already burdened agricultural system, new mechanisms for economic incentives for improving the efficiency of water use must be applied. Present water laws are actually a deterrent to better water management because any change in water use practices that results in a water savings might cause a loss of a portion of a water right, which is considered very valuable to an irrigated agriculture.

The results of this study indicate that canal and lateral lining in the test area reduced salt inflows to the Colorado River by about 4700 tons annually. The bulk of this reduction is attributable to the canal linings, but clearly indicated is the greater importance of lateral linings. The length of laterals, including farm head ditches, is about ten times greater than the length of canals. The economic benefits to the lower basin water users alone exceed the costs ($350,000 construction plus $70,000 administration) of this project. Consequently, it seems justifiable to conclude that conveyance lining in areas such as the Grand Valley, where salt loadings reach 8 tons or more per acre, are a feasible salinity control measure. The local benefits accrued from reduced maintenance, improved land value, and other factors add to the feasible nature of conveyance linings as a salinity management alternative.

SECTION II

RECOMMENDATIONS

Although the results of this study indicate to some degree the effects of other salinity control practices, it is important to realize that not enough of the technical information concerning these alternatives to sufficiently fill the existing gaps in present day knowledge has been provided. Therefore, certain of these practices should be evaluated in the valley before a final salinity control plan is formulated.

One important salinity control study that should be undertaken is irrigation scheduling in conjunction with field tile drainage. This type of study would not only serve to demonstrate the effectiveness of irrigation scheduling in reducing salinity, but also evaluate the feasibility of field drainage for salinity control and land reclamation. During a study such as this, considerable insight could also be gained concerning methods to improve the basin irrigation techniques, although further investigation may be desirable to completely define the problem and solutions.

The most pressing need in basin technology is water quantity and quality models capable of predicting the effects of salinity control programs. Specifically, a model of this nature must be capable of considering the ionic exchange and precipitation in the soil profile. In order to accomplish this level of modeling, additional research should be conducted to evaluate the ionic movements and exchanges in the soil moisture medium.

A valley authority representing all pertinent local interests should be formulated. This organization would serve to promote the investigation of both physical and institutional changes necessary to control salinity from Grand Valley. In addition, it should coordinate a plan for salinity control in the valley based upon an integrated scheme of a multitude of available salinity measures.

Further, the question of allocation of the excess water derived from more efficient management programs should be resolved, possibly by economic incentives for abandoning, selling, leasing, or renting the unused portion of the water right. Because the institutional structure of present water laws poses such an immense constraint to effective water management, a study should be undertaken to evaluate possible changes in the interpretation of state water laws to provide the necessary incentives for improved water management.

Finally, since rehabilitation of the irrigation system is a necessary part of any future salinity control program, it is suggested that alternate types of linings for water conveyance channels be given consideration to determine if local benefits can be increased. Specifically, the high costs of concrete and gunnite may not be as desirable in terms of total costs and benefits as a lining of lower initial cost, but with somewhat higher maintenance costs.

SECTION III

INTRODUCTION

Statement of the Problem

Salinity is the most pressing problem facing the future development of water resources in the Colorado River Basin (Fig. 1). Because of the progressive deterioration in mineral quality towards the lower reaches, the detrimental effects of using an increasingly degraded water are first seen in the lower basin. As a result of the continual development in the upper basin, most of which will be diversions out of the basin to meet large municipal and industrial needs, water ordinarily available to dilute the salt flows will be depleted from the system, causing significant increases in salinity concentrations throughout the basin. The economic penalty resulting from a use of lower quality water will be incurred by those users in the lower system. The U.S. Environmental Protection Agency (37) has estimated that the present economic losses from salinity are $16 million annually. If water resources development proceeds as proposed without implementing a salinity control program, the average annual economic detriments (1970 dollars) would increase to $28 million in 1980 and $51 million in 2010 (37). These damages do not reflect costs to Mexico.

A more detailed examination of the basin-wide problems is summarized in Fig. 2 which clearly demonstrates the necessity of attacking salinity basin wide. As indicated, the bulk of the salt loads passing into the lower reaches is attributable to the upper basin. Salinity management in the upper basin must therefore concern itself with the aspect of salt loading in the river system from municipal, industrial, agricultural and natural sources. The other aspect, which is the salt concentrating effects, is related to consumptive use, evaporation, and transbasin diversions. Although several methods of controlling salinity, such as phreatophyte eradication (although controversial from a wildlife standpoint) and evaporation suppression on reservoirs, are desirable, the most feasible solutions are in reducing inflows from mineralized springs and more efficient irrigation practices. In any case, the salinity management objectives in the upper basin must necessarily be concerned with a reduction in the total salt load being carried to the lower basin in order that the detrimental salinity effects anticipated from further development can be limited. Salinity

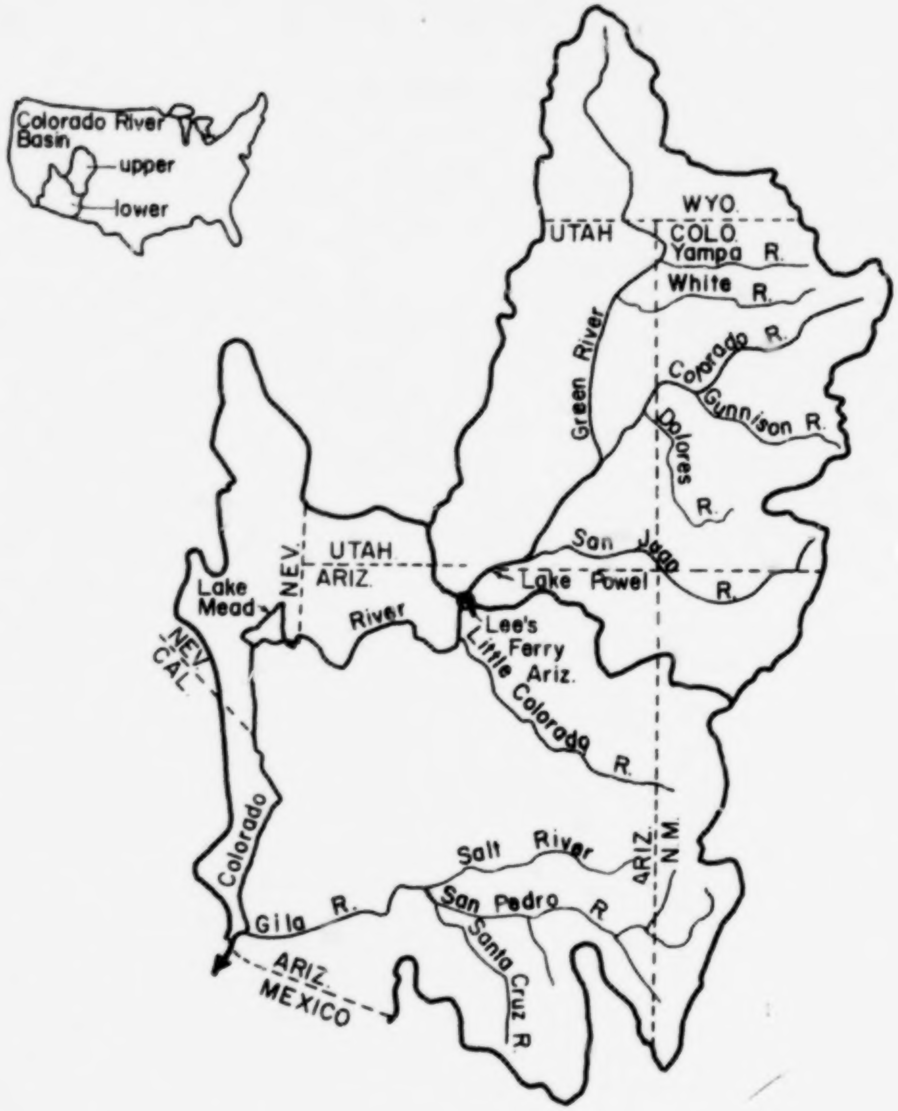

Colorado River Basin
upper
lower
WYO.
UTAH
COLO.
Yampa R.
White R.
Green River
Colorado R.
Gunnison R.
Dolores R.
San Juan R.
UTAH
ARIZ.
NEV.
Lake Powel
Lake Mead
River
Lee's Ferry Ariz.
Little Colorado R.
NEV. CAL.
Colorado
Salt River
ARIZ.
N.M.
San Pedro R.
Santa Cruz R.
Gila R.
ARIZ.
MEXICO

Fig. 1. The Colorado River Basin.

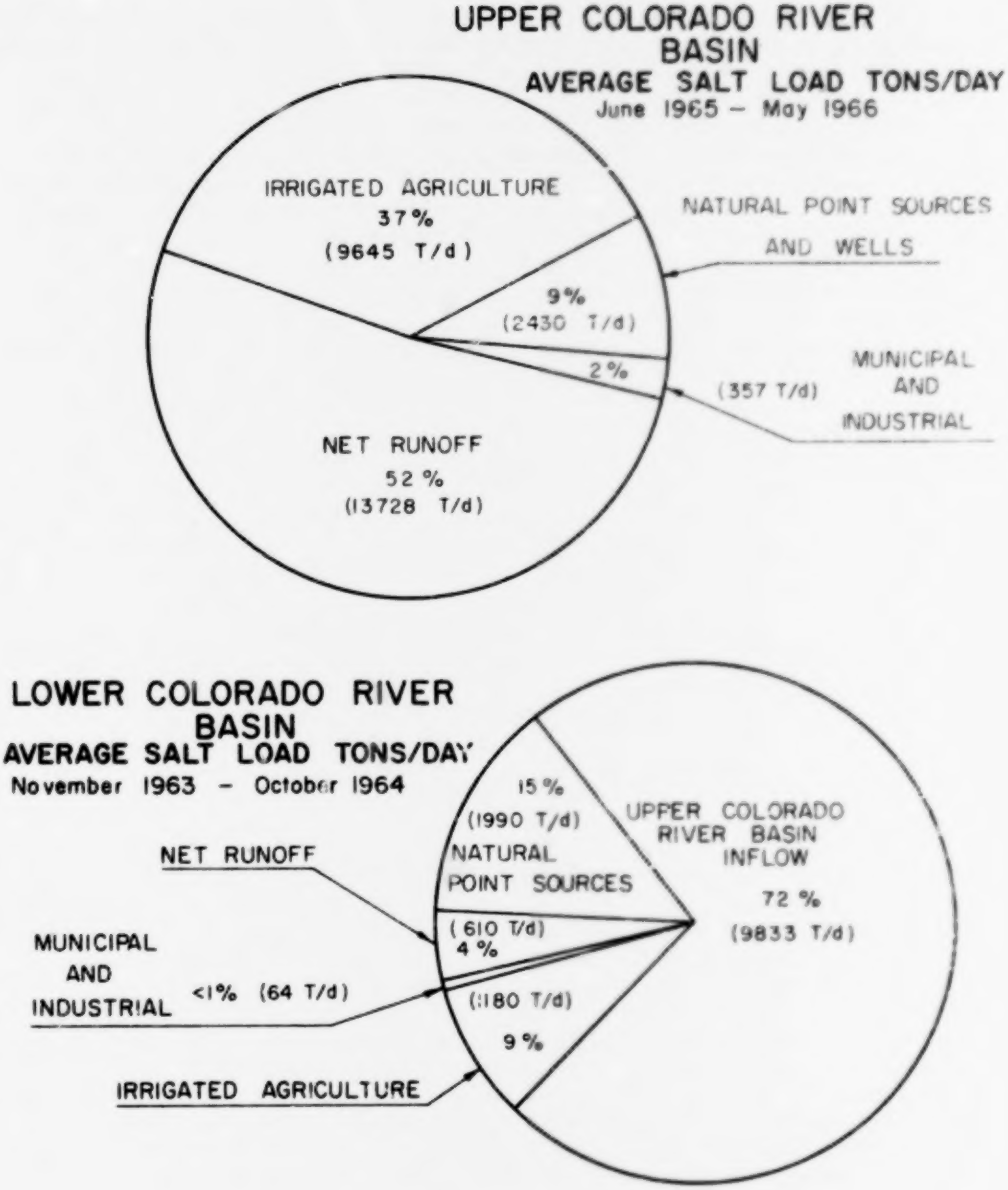


Fig. 2. Relative magnitude of salt sources in the Colorado River Basin (36).

control must be practiced at all locations in the basin if the economic losses to downstream users are to be minimized.

Since the Colorado River Basin is not a rapidly growing municipal and industrail area, the pollution problems are primarily associated with agriculture, as illustrated in Fig. 2. Thus, a major aspect of reducing the salt inputs in the upper basin must be the effective utilization of the water presently diverted for irrigation by comprehensive programs of conveyance channel lining, increasing irrigation efficiency on the farm, improved irrigation company management practices, and more effective coordination of local objectives between the various institutions in the problem areas. Salinity is no longer a local problem and should be considered regionally. In irrigated areas, it is necessary to maintain an acceptable salt balance in the crop root zone which requires some water for leaching. However, when irrigation efficiency is low and conveyance seepage losses are high, the additional deep percolation losses are subject to the highly saline aquifers and soils common in the basin and result in large quantities of salt being picked up and carried back to the river system. Therefore, a need exists to delineate the high input areas and examine the management alternatives available to establish the most effective salinity control program. Probably the most significant salt source in the upper basin is the Grand Valley area (Fig. 3) in west central Colorado, which was selected for this study in order to evaluate conveyance lining as a possible salinity control practice.

The Study Area

The Colorado River enters the Grand Valley from the East, is joined by the Gunnison River at Grand Junction, Colorado, and then exits to the West. The contribution to the total salt flows in the basin from this area, illustrated in Fig. 4, is highly significant. The primary source of salinity is from the extremely saline aquifers overlying the marine deposited Mancos shale formation. The shale is characterized by lenses of salt in the formation which are dissolved by water from excessive irrigation and conveyance seepage losses when it comes in contact with the Mancos shale formation. The introduction of water through these surface sources percolates into the shallow ground water reservoir where the hydraulic gradients it produced displace some water into the river. This displaced water has usually had sufficient time to reach chemical equilibrium with the salt concentrations of the soils and shale. These factors also make the Grand Valley an important study area, since

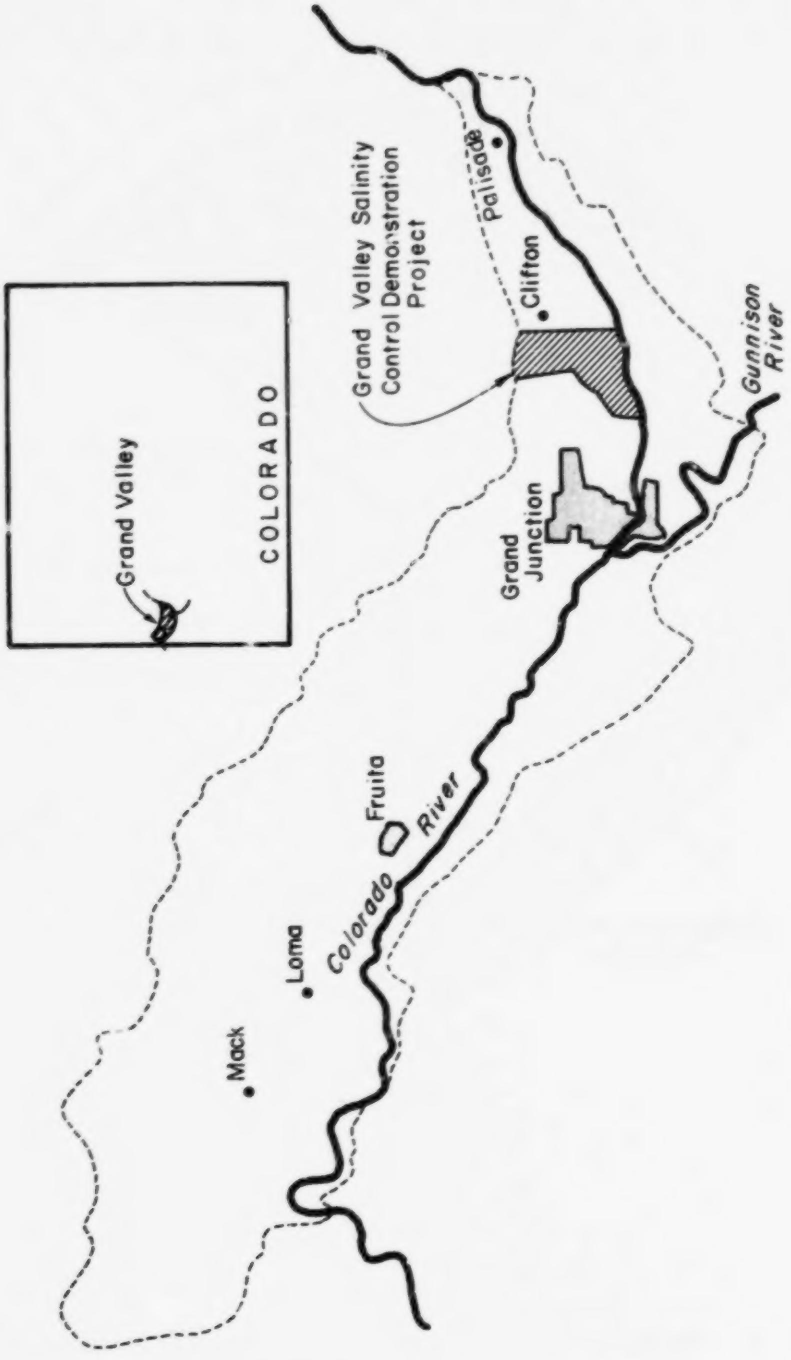

Grand Valley
COLORADO
Grand Valley Salinity Control Demonstration Project
Palisade
Clifton
Gunnison River
Grand Junction
Fruita
Colorado River
Loma
Mack

Fig. 3. The Grand Valley, Colorado.

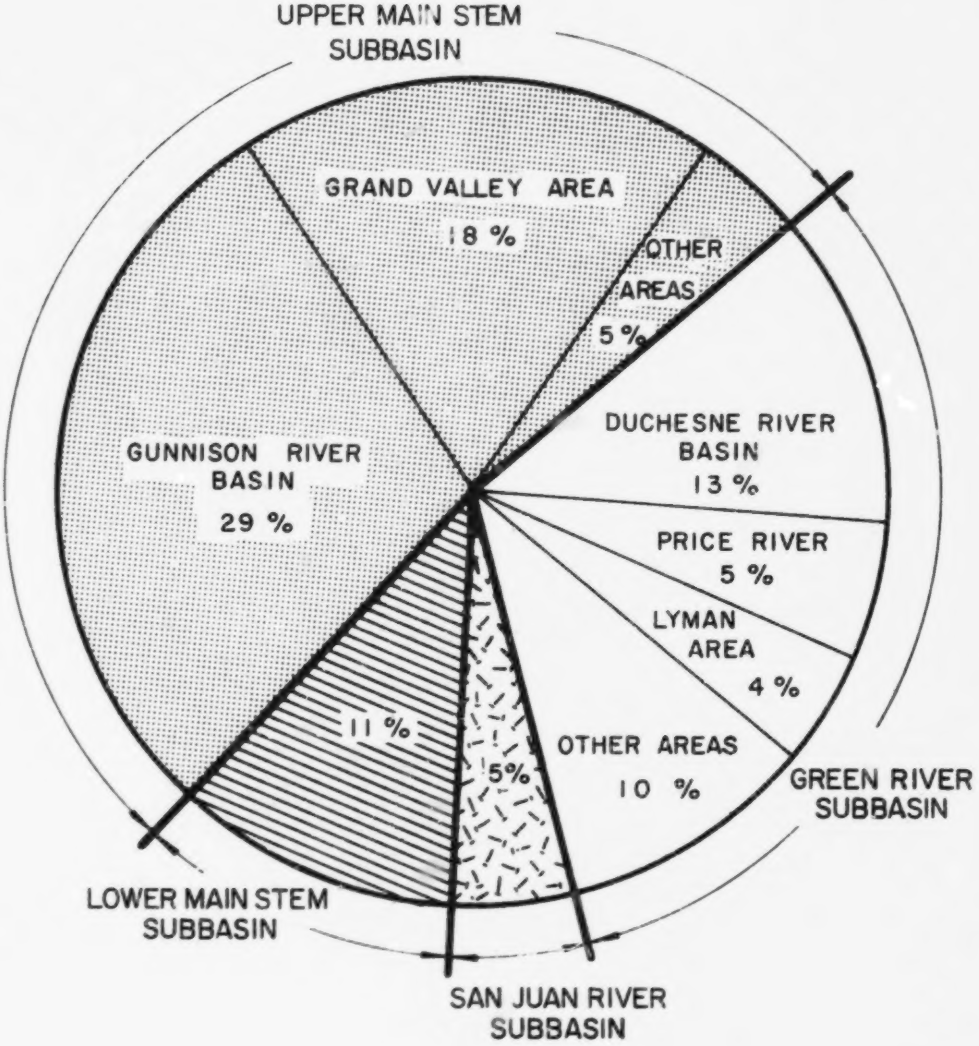


Fig. 4. Relative magnitude of agricultural salt sources in the Colorado River Basin (36).

the conditions encountered in the valley are common to many locations in the basin.

Purpose and Scope of the Study

Aside from the numerous studies in the Grand Valley to evaluate local conditions, this effort, the Grand Valley Salinity Control Demonstration Project, is the first study conducted in the area to determine the effect of a salinity management practice on conditions in the basin. The project was funded on a matching fund basis by the Environmental Protection Agency in conjunction with the Grand Valley Water Users Association, Palisade Irrigation District, Mesa County Irrigation Company, Grand Valley Irrigation Company, Redlands Water and Power company, and the Grand Junction Drainage District to further the development of pollution control technology in the basin. Each of these entities had representatives on the Board of the Grand Valley Water Purification Project, Inc., which was formed to contract with the Federal government to conduct this demonstration project. The objectives of the project include:

(1) Demonstration of the feasibility of reducing salt loading in the Colorado River system by lining conveyance channels to reduce unnecessary ground water additions.

(2) Extension of the results of this study to evaluate the method for applicability to the problem in the Grand Valley and upper basin.

The project is comprised of three study areas selected for their different characteristics commonly found in the valley. Area I, shown in Fig. 5, was chosen as an intensive study area in which the bulk of the investigation was to be conducted and also includes most of the construction effort. This area was designated for detailed investigations regarding effects of conveyance linings on the water and salt flow systems in an irrigated area. The intensive study area was selected for its accessibility in isolating most of the important hydrologic parameters, but had the important advantage that it allowed five irrigation companies to participate in one unit. Area II was selected because it represented a different land form several miles west of Area I along a short section of the Grand Valley Canal where high seepage losses had resulted in a severe drainage problem. Area III is located along a section of the Redlands First Lift Canal, which is supplied from the Gunnison River and was selected to evaluate the effect of different drainage and soil types. Both Areas II and III were to be studied with sufficient

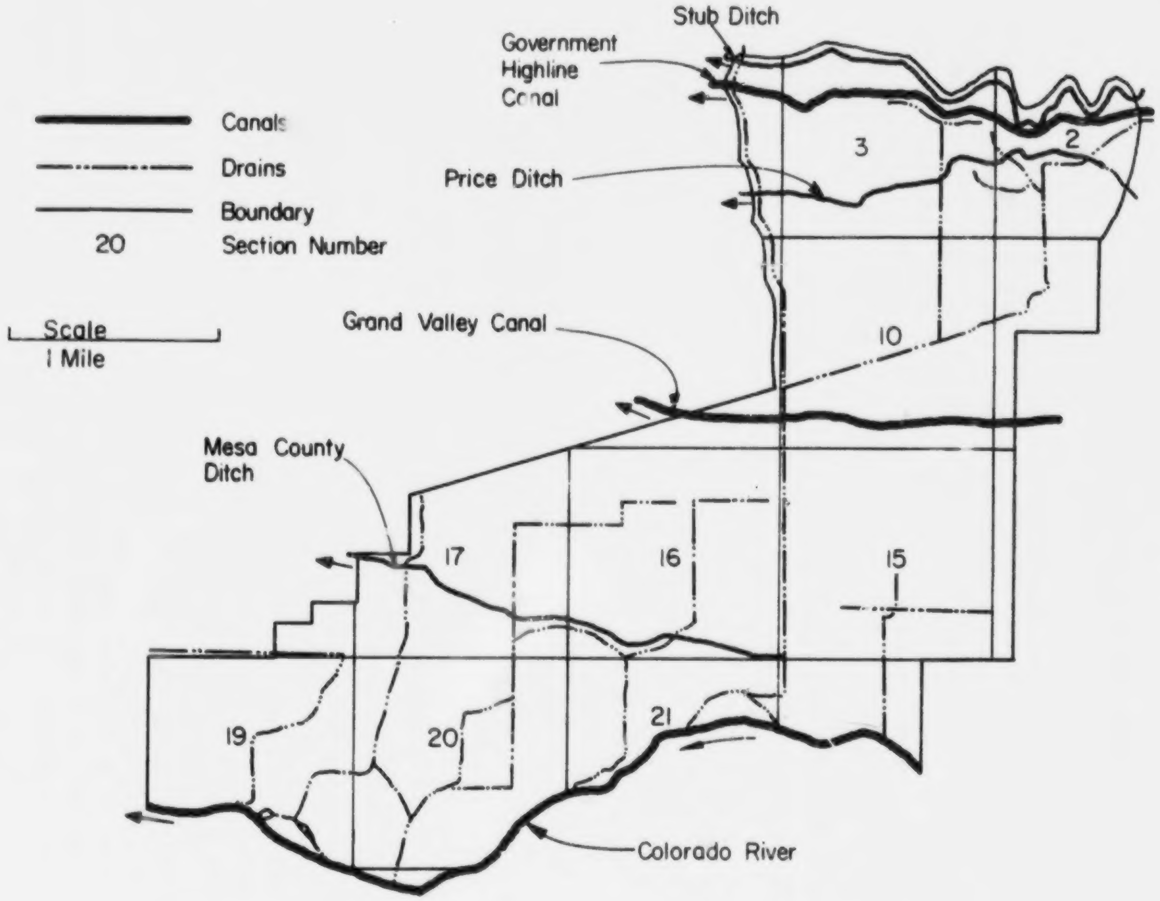

Stub Ditch
Government Highline Canal
Canals
Drains
Boundary
20 Section Number
Price Ditch
3
2
Scale
1 Mile
Grand Valley Canal
10
Mesa County Ditch
17
16
15
19
20
21
Colorado River

Fig. 5. Intensive study area, Area I, of the Grand Valley Project.

data to confirm the results in Area I and involved a minimum number of observations.

Method of Approach

The procedure outlined for execution of the project consisted of a two-phase study. Phase 1 was planned to evaluate the conditions in the study areas prior to the construction of the lining. These results have been reported (29). Phase 2 consisted of re-evaluating the conditions after the lining had been completed. In both cases, the study was conducted to collect and analyze sufficient data to define in detail both water and salt flow systems.

Although the pre-construction analysis has been reported, all relevant information is presented herein in order to provide a complete description of the results and conclusions of this study.

Earlier investigations concerned with irrigation and drainage in Grand Valley are summarized herein, as well as a history of irrigation development in the valley.

The pre-construction and post-construction evaluation is based upon a hydro-salinity model having two basic sub-systems - surface water and ground water. The field data collection is designed to define the components of the water and salt budgets.

SECTION IV

THE GRAND VALLEY AREA

Most salinity measures which could be considered may be found to be very poorly conceived without a thorough understanding of the physical and social conditions in an area. The attitudes of local people are important management considerations and for the most part these attitudes are easily traced to events surrounding the development of the area. In addition, it is necessary to be aware of the natural characteristics of an area so that restrictions are not imposed which would destroy an area as a functional community. And finally, the institutional structure of an area should be known before control measures are undertaken so that regional alternatives for meeting standards remain flexible. In consideration of these aspects, this section will briefly describe the development of Grand Valley and present physical conditions.

Exploration and Settlement

Although numerous hieroglyphics and abandoned ruins testify to occupation of the Colorado River Basin long before settlement began, the first people encountered in the Grand Valley were the Ute Indians. The first contact these peoples had with white men was recorded in 1776 when an expedition led by Fathers Dominiquez and Escalante passed north of what was later to be Grand Junction and across the Grand Mesa (12). The region was subsequently visited by fur trappers, traders and explorers. In 1839 one such trader named Joseph Roubdeau built a trading post just upstream from the present site of Grand Junction.

In 1853, Captain John W. Gunnison led an exploration party into the Grand Valley from up the Gunnison River Valley in search of a feasible transcontinental railroad route (2). As Captain Gunnison and his party traversed the confluence of the Colorado and Gunnison Rivers, an error was made by the expedition recorder as to the proper naming of the rivers. Beckwith referred to the Gunnison River as the Grand River and the Colorado River as the Blue River, or "nah-un-Kah-rea," as it was known to the Indians. The mistake was later corrected, however, since the Colorado River was known as the Grand River as early as 1842 (10). Field surveys conducted by Hayden (13) in 1875 and 1876 found only the Ute Indians in the valley, and skirmishes with some of the hostile Utes cut short the 1875 expedition. As a result of the Meeker Massacre of 1879, the Utes were forced to accept a treaty moving them out of Colorado and onto reservations in eastern Utah. After the completion of the Utes' exit in September 1881, the valley was immediately opened up for settlement with the first ranch staked out on September 7, 1881 near Roubdeau's trading post. Later that year on September 26, George A. Crawford founded Grand Junction as a townsite and formed the Grand Junction Town Company, October 10, 1881. On November 21, 1882 the Denver and Rio Grande Railroad narrow-gage line was completed to Grand Junction via the Gunnison River Valley and thus assured the success of the settlement.

Water Resource Development

Early exploration concluded that the Grand Valley had limited potential for agriculture since the terrain appeared very desolate. A great deal of appreciation for this judgment can be acquired just passing through the area and noting the landscape outside the irrigated agricultural boundaries. In 1853, Beckwith described the valley as, "The Valley, twenty miles in diameter, enclosed by these mountains, is quite level and very barren except scattered fields of greasewood and sage varieties of artemisia - the margins of the Grand (Gunnison) and Blue (Colorado) Rivers affording but a meager supply of grass, cottonwood, and willow." Soon after the settlement began, it was realized that the climate could not support a non-irrigated agriculture. As a result, irrigation companies were organized to divert water from the river for irrigation. An attempt has been made in the following paragraphs to describe this development in the Grand Valley.

Grand Valley Irrigation Company

The Grand Valley Irrigation Company owns and operates the Grand Valley Canal, which at the present time serves 46,678 acres of land which can be broken down by type of land use as listed in Table 1 (39).

The present Grand Valley Canal system comprising approximately 110 miles of canals and subcanals is the result of a consolidation of the Grand River Ditch Company, Grand Valley Canal Company, Mesa County Ditch Company, Pioneer Extension Ditch Company, and the Independent Ranchmen's Ditch Association. The construction of what is now the main line Grand Valley Canal probably began in 1882, since the original

Table 1. Land use under the Grand Valley Canal system (including Mesa County Ditch).

Use	Acreage	Total	Percent
Corn	6828		
Sugar Beets	1726		
Potatoes	96		
Tomatoes	133		
Truck Crop	147		
Barley	2373		
Oats	1530		
Wheat	63		
Alfalfa	5454		
Native Grass Hay	84		
Cultivated Grass and Hay	1621		
Pasture	3962		
Wetland Pasture			
Native Grass Pasture	587		
Orchard	555		
Idle	4557		
Other Cropland	11		
Subtotal		29,727	63.7
Farmsteads	1300		
Residential Yards	53		
Urban	3925		
Stock Yards	262		
Subtotal		5,540	11.9
Refineries	40		
Other Industrial	642		
Subtotal		682	1.5
Open Water Surfaces	798		
Subtotal		798	1.6
Cottonwoods	343		
Salt Cedar	1402		
Willows	138		
Rushes or Cattails	433		
Greasewood	4023		
Sagebrush or Rabbitbrush			
Grasses and Sedges	1		
Subtotal		6,340	13.6
Precipitation Only	3591		
Subtotal		3,591	7.7
Total		46,678	100.0

priority is dated August 22, 1882, although A. J. McCune who was the engineer for the Grand River Ditch Company filed a statement with the clerk and recorder of Mesa County, Colorado on April 5, 1883 that construction commenced January 10, 1883 (27). At this time, the ditch was owned by Matt Arch, E. S. Oldham, William Oldham, John Biggles, and William Cline who planned for a capacity of about 786 cfs. However, the early development times were uncertain and the company, like many others, was facing financial trouble so was sold to the Traveler's Insurance Company which also acquired title to the other four companies now making up the system. On January 29, 1894 the Grand Valley Irrigation Company was incorporated when the Certificate of Incorporation was filed with the Secretary of State's office and the title was acquired from the insurance company.

The water rights of an agricultural area in the western United States often are complex due to the nature of system evolution necessary to develop an area. In general, such is the case in the Grand Valley area. Upon the organization of the company, an application was made for an adjudication of its water rights from the Colorado River. The application for the Grand Valley Canal was awarded a decree of 520.81 cfs July 27, 1912, with the priority date of August 22, 1882, which was priority No. 1 on the Colorado River. The hearings which led to the adjudication established an irrigated acreage of 30-35 thousand acres with a probable 20% system loss rate. On July 25, 1914, the First Enlargement of the Grand Valley Canal was awarded Priority No. 358 and dated July 23, 1914 for 195.33 cfs, of which 75.86 cfs is conditional upon the addition of 4,661.25 acres to the system.

Although the original decree was based on an estimated acreage of 30-35,000 acres, later investigation revealed the acreage was slightly less than 40,000 acres, plus the additional 4,661.25 acres not yet developed, for a total of about 44,000 acres. If the usual 200-day irrigation season is experienced, this water right amounts to approximately 5.76 acre-feet per acre, from which an estimated 20% loss rate of 1.05 acre-feet per acre leaves about 4.71 acre-feet per acre for irrigation.

The company is organized in the corporation format. The division of water among irrigators is on the basis of shares of the capital stock of the company comprising a total of 48,000 shares. Thus, an individual holding one share of stock would be entitled to 4.23 acre-feet of water at his turnout. It should be noted that this figure does not include the loss rates of the company. In addition, these figures do not include the 75.86 cfs of conditional water. In 1971, the water assessment was $15.00 for the first share and $2.40 for each additional share. Occasionally, some assessments cannot be paid, in which case a period is given for the irrigator to reclaim the water share, after which grace period the share is sold at auction.

Grand Valley Project

The Grand Valley Project which now serves water to four irrigation companies, the Grand Valley Water Users Association, the Orchard Mesa Irrigation District, Palisade Irrigation District (Price Ditch), and the Mesa County Irrigation District (Stub Ditch), is the result of considerable effort and a long series of disapointments. Before describing the details of the companies themselves, it is interesting to explore the history of development leading to the present day conditions (1).

When the Ute Indians moved out of the valley and the first benefits of irrigation were being realized, the opportunity for further development of irrigation above and beyond the Grand Valley Canal could be seen. The fruit industry prospered almost from the time early settlers experimented with deciduous fruit culture that eventually gave the valley a reputation as a high quality orchard locality. However, neither the capital nor the authorization to develop additional lands was available until 1902 when the Federal Reclamation Act was passed. Although the act was passed, no provision for operation was made. The Bureau of Public Surveys was charged with the responsibility to investigate locations which could be developed. Early in September 1902, J. H. Mathis arrived in Grand Junction with a small party of engineers to survey the Grand Valley for its feasibility as an experimental reclamation project.

When the investigation was almost completed, an event occurred which is probably the worst disaster to occur in the valley. T. C. Henry, unscrupulous promoter from Denver, arrived on the scene and convinced local people he could finance, build and operate a system far better than could the government. By a majority of two votes, the local citizens accepted the proposal, causing the government to withdraw, even though the engineers had found Grand Valley to be a feasible location for a reclamation project.

In 1904, T. C. Henry was forced to admit that he had neither a plan nor a prospect for action in the Grand Valley. Fortunately, the efforts of the people were sufficient to revive government interest in the potential project. In June 1907, James R. Garfield, Secretary of the Interior, officially approved the project and allocated $150,880 to begin the permanent survey of the project. The project at this point entailed what is now known as the Government Highline Canal and its construction was increasingly important to the local people because of the continued success agriculture had been enjoying. In fact, the future of the fruit industry looked so promising that one six-acre peach orchard sold for $24,000, or $4,000 per acre.

The Grand Valley was not yet through with T. C. Henry. In 1907, he contacted the Magenheimer Brothers of Chicago who had been successful in dredging operations along Lake Michigan. Since the exploitation of irrigation projects was both a popular and a successful business, they took up the line. Together with four local promoters, they organized a district (later to become the Orchard Mesa Irrigation District) covering about 10,000 acres on the south side of the river. In addition, plans were being made by the Magenheimers to take over the remainder of the land of the government project (Water Users Association).

The increasing demand for the project prompted the local people in the Association to submit a proposal to provide $125,000, if the government would match this amount, for starting construction. In October 1908, Secretary Garfield accepted the challenge and approved the proposal. Local pledges in the form of work allocations were soon called upon and construction began; but at four o'clock on May 4, 1909, the same day work started, the new Secretary of the Interior, R. A. Ballenger, suspended construction with no reason stated. Ballenger had been asked by Senator Henry M. Teller from Denver to abandon the project because private capital was available for the work and in such cases the government should not interfere. This information had been given the Senator by a prominent law firm of Denver which was representing the Magenheimer-Henry combination. The local people sent representatives to Washington to investigate the work stoppage and just happened to visit Senator Teller, who then told them what had happened. Unfortunately, a great deal of effort by numerous individuals failed to sway Ballenger, who still would not give reason for his attitude. In 1911, Ballenger resigned and was succeeded by Walter L. Fisher who finally gave his approval; and on October 23, 1912 work was again initiated. Thus, the Association escaped falling into the hands of the Magenheimers.

The construction of the Orchard Mesa system was begun by placing a $163 per acre cost on the 10,000 acres of land, with six percent interest bearing bonds and warrants. The system was so poorly constructed that portions failed before the system was completed. This was all made possible because the Magenheimers had gained control of the Board of Directors, and although the idea was met with bitter opposition by local people the election carried. From that time on, T. C. Henry and the Magenheimers embezzled the farmers and the district to the point of final collapse. Phony construction companies, phony construction and phony personnel finally brought the district near financial collapse.

Finally, an earnest plea was made to the government that rehabilitation of the Orchard Mesa system be included among the construction efforts with the Association. The plea was heeded and the system saved, a cost which is still being repaid.

The efforts of T. C. Henry and the Magenheimer Brothers are not unlike many that have occurred throughout the West. Many people were ruined by their actions and the memory is still very real. It is very fortunate that the irrigation companies in the Grand Valley and many other areas are still operating.

With this abbreviated history surrounding the Grand Valley Project, the operation and water rights of the 4-canal system will be discussed separately.

Grand Valley Water Users Association. The Grand Valley Water Users Association was incorporated February 7, 1905 and later renewed the incorporation September 11, 1945. It operates the Government Highline Canal which serves about 44,416 acres of irrigable land. In addition, the Association diverts 800 cfs during the non-irrigation season for power development through a siphon across the Colorado River shortly below the main diversion. During the irrigation season, 400 cfs is used for power development, with the remaining 400 cfs passing through the irrigation pumps. The power generated with this water is sold to the Public Service Company of Colorado to help pay the debt on the original project.

A summary of the water rights is listed in Table 2 and will be referred to later in the descriptions of the other canals.

The land use survey conducted in 1969 under the Government Highline Canal, which is listed in Table 3 (39), varies somewhat from that originally listed by the early land surveyors. However, the classification systems are also different.

The operation of the Grand Valley Water Users Association is on a corporation basis, and although stock is registered in the County Recorder's Office, none has ever been issued. The Bureau of Reclamation classified the land into one of five categories: Class 1 - good orchard; Class 1A - young

Table 2. Water right decrees for the Grand Valley Project.

Name of Ditch		Original Appropriation Date	Decree Allowed (cfs)	Use of Right
(1)	Orchard Mesa Power Canal	3- 6-89	110.70	Irrigation
(2)	Palisade Irr. Dist.	10- 1-89	573.00	Pumping
(3)	" " "	" "	80.00	Irrigation
(4)	Orchard Mesa Power Canal	8- 2-98	139.30	Irrigation
(5)	E. Palisade Irr. Dist.	10- 1-00	10.20	Irrigation
(6)	Mesa County Irr. Dist.	7- 6-03	627.00	Pumping
(7)	" " "	" "	40.00	Irrigation
(8)	Mann Pumping System	9-10-03	1.00	Irrigation
(9)	Orchard Mesa Irr. Dist.	10-25-07	195.00	Irr, Pump
(10)	" " "	" "	75.00	Irrigation
(11)	" " "	" "	180.00	Conditional
(12)	Grand Valley Project	2-27-08	730.00	Irrigation
(13)	" " "	" "	400/800	Power
(14)	Rose Point Power Canal	7- 2-10	113.25	Irrigation
(15)	Orchard Mesa Irr. Dist.	4-26-14	100.00	Conditional
(16)	Palisade Irr. Dist.	6- 1-18	23.50	Irrigation

Table 2. (Continued)

Comments

(1) Abandon, land now in Orchard Mesa Irr. Dist., 10 cfs irr., rest pumping, rights not transferred to District.

(2) Power plant abandon, decree usable only with approval of Bureau of Reclamation.

(3) Decree delivered by Gov't Highline Canal, point of diversion changed by decree of 7-25-41.

(4) Same as (1).

(5) Former steam pumping plant, now gravity from Orchard Mesa Power Canal, Orchard Mesa Irr. Dist. owns decree.

(6) Same as (2).

(7) Decree now delivered by Gov't Highline Canal by gravity and pumping, point of diversion not formally changed.

(8) Former steam pump from river, now pumped from Orchard Mesa Power Canal, electric motor.

(9) Now diverted through Gov't Highline Canal, but through same pumping plant, point of diversion changed.

(10) Same as (9).

(11) Same as (9), made absolute in decree of 7-25-41, 130.0 cfs power, 50 cfs irrig.

(12) Quantity fixed in decree of 7-25-41 as above, same applies for power and domestic.

(13) Quantity fixed in decree 7-25-41 with priority date as above, 400 cfs irrigation season, 800 cfs non-irrigating season.

(14) Abandon, decree property of Orchard Mesa Irr. Dist., no change in point of diversion.

(15) Conditional water claimed for irrigation, none claimed for pumping water.

(16) Date of this decree is date of change of point of diversion to Gov't Highline Canal (3). This decree provides for laterals fed directly from project canal to Palisade lands.

Table 3. Land use under the Government Highline Canal in 1969.

Use	Acreage	Total	Percent
Corn	5979		
Sugar Beets	3452		
Potatoes	95		
Tomatoes	31		
Truck Crop	161		
Barley	1644		
Oats	963		
Wheat	15		
Alfalfa	7019		
Native Grass Hay			
Cultivated Grass and Hay	450		
Pasture	1533		
Wetland Pasture	11		
Native Grass Pasture	47		
Orchard	695		
Idle	2948		
Other Cropland	126		
Subtotal		25,169	56.7
Farmsteads	685		
Residential Yards	28		
Urban	759		
Stock Yards	157		
Subtotal		1,629	3.7
Refineries	0		
Other Industrial	0		
Subtotal		0	0
Open Water Surfaces	635		
Subtotal		635	1.4
Cottonwoods	612		
Salt Cedar	2262		
Willows	122		
Rushes or Cattails	344		
Greasewood	3211		
Sagebrush or Rabbitbrush	3		
Grasses and Sedges			
Subtotal		6,554	14.8
Precipitation Only	10,429		
Subtotal		10,429	23.4
Total		44,416	100.0

orchard; Class 2 - good agricultural lands; Class 3 - fair agricultural; and Class 4 - poor agricultural lands. On the basis of this classification, a farmer can sign up for his irrigable acreage which allows him at the present time four acre-feet per acre, above which (if the supply is available) he is charged for the excess. There are restrictions on the time rate of delivery, however, which are imposed when the supply is limited. This restriction is usually a limit of 1 cfs per 40 acres, and sometimes as low as 0.75 cfs per 40 irrigable acres; this practice has, in the past, been necessary only during the peak use months of the summer. During the fall and spring, water is usually delivered on a demand basis. It should be further noted that although a farmer signs up for a fixed area of irrigable acreage, he may apply the water as he wishes on his property. In addition, when the property is sold, he is allowed only to sell water for the irrigable acreage being sold, so in effect the water is tied to the land and non-shareholders or outside acreage cannot obtain Association water.

The price of water in the Association is based on an assessment of the irrigable acreage on the following basis: In 1971, for example

$1.40/acre repayment of government land
$4.00/acre for operation and maintenance
$1.20/acre-ft of excess used over 4 acre ft/acre allocated.

The minimum assessment is $20 per farm. In 1971, there were approximately 24,000 acres assessed as compared with the 25,000 irrigable acres (39).

Orchard Mesa Irrigation District. The Orchard Mesa Division of the Grand Valley Project was formed by request of the people of the Orchard Mesa Irrigation District when the prior operation was facing bankruptcy. The District was organized under the 1905 Colorado Statute covering irrigation districts, which was later revised to the 1921 Colorado Law.

The operation of the district in many ways is similar to the Association in that the water duty and land classification are the same. The Orchard Mesa Irrigation District is now provided water through a siphon diversion from the Government Highline Canal into the Orchard Mesa Power Canal. During the irrigation season, 1/2 of the 800 cfs in the canal is diverted through the Orchard Mesa Irrigation District pumps which lift 80 cfs 40 feet into the Orchard Mesa #2 Canal and 60 cfs 130 feet into the Orchard Mesa #1 Canal.

The price of using water in the District is based again on the land classification. However, the procedure is similar to the assessment technique used by county government. The Board of Directors for the District prepares a budget consisting of repayment for irrigation system rehabilitation by the government, operation and maintenance, etc. Then, the budget is approved by the Tax Commission of Colorado and the State Auditor. The valuation of land is then checked with the County Assessor, from which a mill levy is set to obtain the money. In 1971, the assessed acreage was 9,199 acres, which was assessed on the following basis:

Class 1	$11.05/acre
Class 1A	8.71/acre
Class 2	8.71/acre
Class 3	7.15/acre
Class 4	5.85/acre

Of the total revenue collected, at a rate of 130 mills, 43 goes to repay the government and 87 for operation and maintenance. The 1969 land use breakdown in the District is summarized in Table 4 (39).

Palisade Irrigation District. The Palisade Irrigation District, with essentially the same organizational format as the Orchard Mesa Irrigation District, operates the Price Ditch. This ditch is supplied 66-68 cfs through a turbine pump just off the Government Highline Canal as it exits through Tunnel No. 3. An additional 24-22 cfs is delivered through turnouts in the Highline Canal, as can be noted in Table 2. The agricultural area served by the Price Ditch is listed in Table 5 (39).

Both the Palisade Irrigation District and the Mesa County Irrigation District were organized independently of the government projects. Their history is somewhat unknown to the writers, but they consolidated their systems with the Highline Canal when it was built, presumably to streamline their operation.

Mesa County Irrigation District. The Mesa County Irrigation District, which operates the Stub Ditch, has an irrigation water right of 40 cfs as listed in Table 2. The operation and organization of this district are similar to the previous five districts mentioned. At the turbine pump serving the Price Ditch, 15 cfs is pumped into the Stub Ditch, with the remaining 25 cfs being diverted directly from the Highline Canal to agricultural lands within the boundaries of the Mesa County Irrigation District. The irrigated land under the Stub Ditch is included in Table 6 (39).

Table 4. Land use in the Orchard Mesa Irrigation District during 1969 (39).

Use	Acreage	Total	Percent
Corn	767		
Sugar Beets	51		
Potatoes	78		
Tomatoes	66		
Truck Crop	53		
Barley	247		
Oats	82		
Wheat	26		
Alfalfa	948		
Native Grass Hay	20		
Cultivated Grass and Hay	213		
Pasture	597		
Wetland Pasture	144		
Orchard	3493		
Idle	909		
Other Cropland	0		
Subtotal		7,694	69.9
Farmsteads	234		
Residential Yards	244		
Urban	703		
Stock Yards	182		
Subtotal		1,363	12.4
Refineries	0		
Other Industrial	0		
Subtotal		0	0
Open Water Surfaces	135		
Subtotal		135	1.2
Cottonwoods	92		
Salt Cedar	116		
Willows	10		
Rushes or Cattails	85		
Greasewood	498		
Sagebrush or Rabbitbrush	32		
Grasses and Sedges	17		
Subtotal		850	7.7
Precipitation Only	964		
Subtotal		964	8.8
Total		11,006	100.0

Table 5. Land use under the Price Ditch during 1969 (39).

Use	Acreage	Total	Percent
Corn	535		
Sugar Beets			
Potatoes			
Tomatoes	2		
Truck Crop			
Barley	263		
Oats	70		
Wheat	22		
Alfalfa	551		
Native Grass Hay	35		
Cultivated Grass and Hay	109		
Pasture	369		
Wetland Pasture			
Native Grass Pasture	198		
Orchard	1575		
Idle	571		
Other Cropland	6		
Subtotal		4,306	79.7
Farmsteads	108		
Residential Yards	163		
Urban	264		
Stock Yards	12		
Subtotal		547	10.1
Refineries	0		
Other Industrial	0		
Subtotal		0	0
Open Water Surfaces	37		
Subtotal		37	0.7
Cottonwoods	10		
Salt Cedar	24		
Willows	40		
Rushes or Cattails	16		
Greasewood	75		
Sagebrush or Rabbitbrush			
Grasses and Sedges	12		
Subtotal		177	3.3
Precipitation Only	337		
Subtotal		337	6.2
Total		5,404	100.0

Table 6. Land use under the Stub Ditch during 1969 (39).

Use	Acreage	Total	Percent
Corn	71		
Sugar Beets			
Potatoes			
Tomatoes			
Truck Crop	33		
Barley			
Oats			
Wheat			
Alfalfa	97		
Native Grass Hay			
Cultivated Grass and Hay	6		
Pasture	43		
Wetland Pasture			
Native Grass Pasture			
Orchard	247		
Idle	111		
Other Cropland	0		
Subtotal		608	78.7
Farmsteads	25		
Residential Yards	5		
Urban	2		
Stock Yards	0		
Subtotal		32	4.1
Refineries	0		
Other Industrial	0		
Subtotal		0	0
Open Water Surfaces	31		
Subtotal		31	4.0
Cottonwoods	4		
Salt Cedar	2		
Willows	7		
Rushes or Cattails			
Greasewood	38		
Sagebrush or Rabbitbrush			
Grasses and Sedges			
Subtotal		51	6.6
Precipitation Only	51		
Subtotal		51	6.6
Total		773	100.0

Redlands Water & Power Company

The Redlands Water & Power Company, a mutual ditch company, irrigates about 3,000 acres southwest of Grand Junction and south of the Colorado River. The water supply is diverted from the Gunnison River in a canal carrying 670 cfs. Six cfs is used for irrigation of lands below the power canal, 610 cfs for power generation, and 54 cfs is pumped to an initial height of 127 feet for irrigation. Small areas in the project are served by higher lifts, the highest being at about 300 feet. Electricity in excess of pumping needs is sold to project settlers and to the Public Service Company. Land use classification resulting from the 1969 survey is listed in Table 7 (39).

Geology

The plateaus and mountains in the Colorado River Basin are the product of a series of uplifted land masses deeply eroded by wind and water. However, long before the earth movements which created the uplifted land masses, the region was the scene of alternate encroachment and retreat of great inland seas. The sedimentary rock formations underlying large portions of the basin are the result of material accumulated at the bottom of these seas. In areas similar to the Grand Valley, the upper portions contain a large number of intertonguing and overlapping formations of continental sandstone and marine shales, as shown in Fig. 6 (31). The lower parts are mostly marine Mancos shale and the Mesa Verde group of related formations. This particular geology is exhibited in about 23 percent of the basin in such common locations as the Book Cliffs, Wasatch, Aquarius, and Kaiparowits Plateaus, the cliffs around Black Mesa, and large areas in the San Juan and Rocky Mountains.

The geology of an area has a profound influence on the occurrence, behavior, and chemical quality of the water resources. In the mountainous origins of most water supplies, a continuous interaction of surface water and ground water occurs when precipitation in the form of rain and melting snow enters ground water reservoirs. Eventually, these quantities of ground water return to the surface flows through springs, seeps, and adjacent soil in regions downstream. A further consequence of such a flow system is the addition of water from streams to the ground water storage during periods of high flows and subsequent return flows during low flow periods. The resulting continuous interaction of surface water and ground water allows contact with rocks and soils of the region which affect the chemical characteristics imparted to the water.

Table 7. Land use under the Redlands Water & Power Company system during 1969 (39).

Use	Acreage	Total	Percent
Corn	124		
Sugar Beets	32		
Potatoes	3		
Tomatoes	17		
Truck Crop			
Barley	18		
Oats	55		
Wheat			
Alfalfa	531		
Native Grass Hay			
Cultivated Grass and Hay	31		
Pasture	1139		
Wetland Pasture			
Native Grass Pasture	115		
Orchard	371		
Idle	610		
Other Cropland	0		
Subtotal		3,046	47.5
Farmsteads	94		
Residential Yards	38		
Urban	713		
Stock Yards	40		
Subtotal		885	13.8
Refineries	0		
Other Industrial	0		
Subtotal		0	0
Open Water Surfaces	63		
Subtotal		63	1.0
Cottonwoods	78		
Salt Cedar	841		
Willows	60		
Rushes or Cattails	9		
Greasewood	213		
Sagebrush or Rabbitbrush	1		
Grasses and Sedges	0		
Subtotal		1,202	18.7
Precipitation Only	1235		
Subtotal		1,235	19.0
Total		6,431	100.0

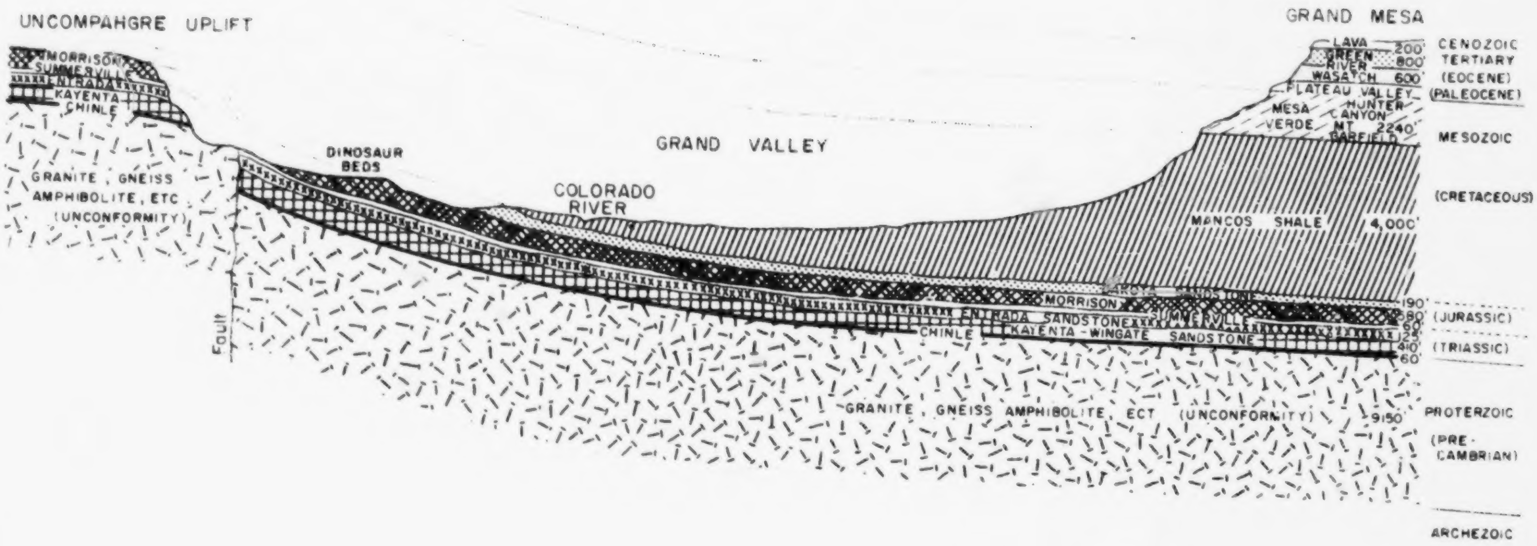

UNCOMPAHGRE UPLIFT
MORRISON
SUMMERVILLE
ENTRADA
KAYENTA
CHINLE
GRANITE, GNEISS AMPHIBOLITE, ETC (UNCONFORMITY)
Fault
DINOSAUR BEDS
COLORADO RIVER
GRAND VALLEY
GRAND MESA
LAVA 200'
GREEN RIVER 800'
WASATCH 600'
PLATEAU VALLEY
MESA VERDE
HUNTER CANYON
MT GARFIELD
2240'
MANCOS SHALE 4,000'
DAKOTA SANDSTONE
MORRISON
SUMMERVILLE
ENTRADA SANDSTONE
CHINLE
KAYENTA - WINGATE SANDSTONE
190'
580'
60'
125'
410'
60'
GRANITE, GNEISS AMPHIBOLITE, ECT (UNCONFORMITY)
9150'
CENOZOIC
TERTIARY
(EOCENE)
(PALEOCENE)
MESOZOIC
(CRETACEOUS)
(JURASSIC)
(TRIASSIC)
PROTERZOIC
(PRE-CAMBRIAN)
ARCHEZOIC

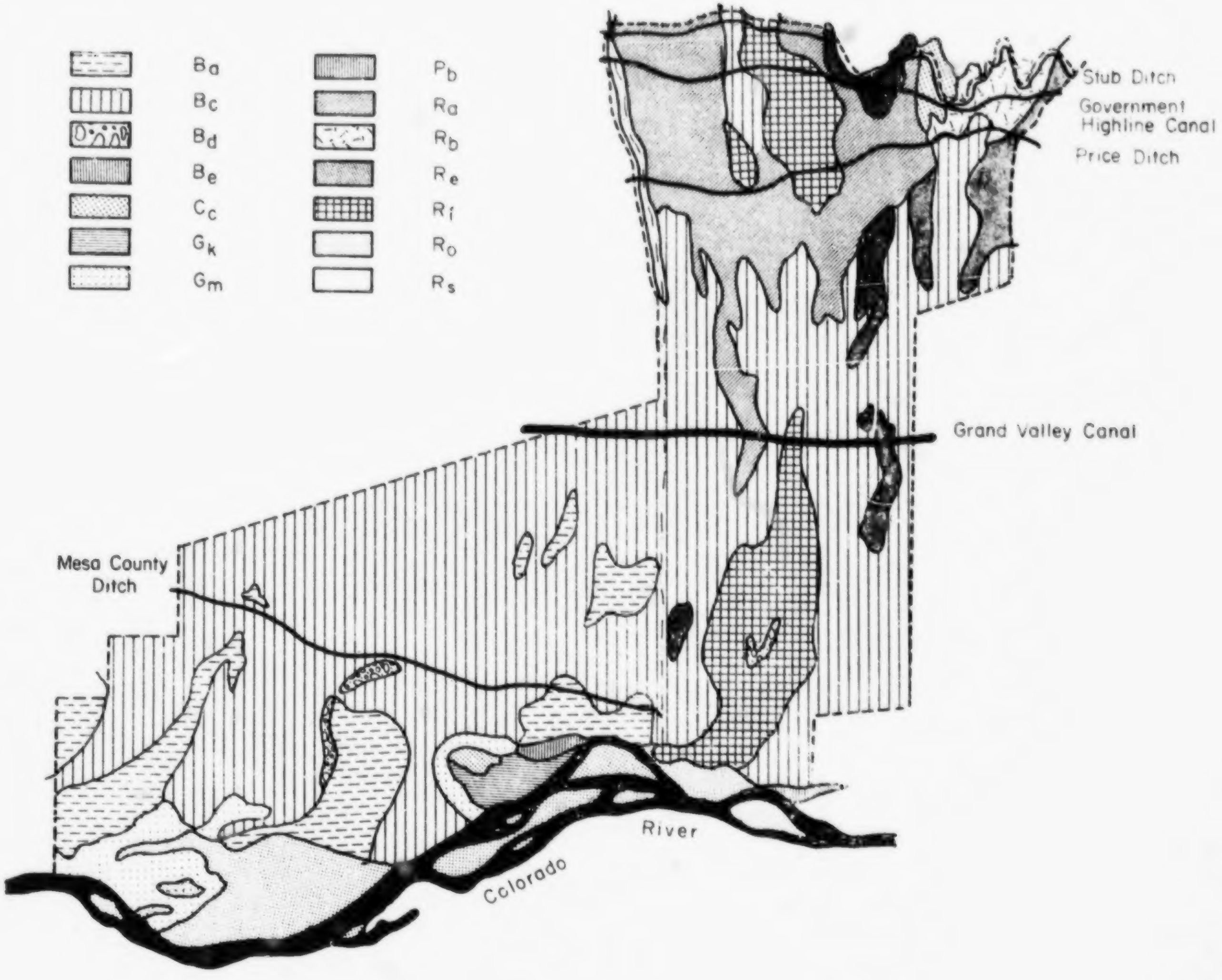
Fig. 6. General geologic cross-section of the Grand Valley (31).

The interior valleys of the basin (the Grand Valley is a good example) do not receive large enough amounts of precipitation to significantly recharge the ground water storage. Usually, the water bearing aquifers are buried deep below the valley floor and are fed in and along the high precipitation areas of the mountains. Shallow ground water supplies are predominately the result of irrigation. Although the water in the consolidated rock formations of the valley region does not contribute significantly to the stream flows as is the case in higher elevations, it does have a pronounced effect on water quality due to the large volumes of natural salts contained in these formations. High intensity thunderstorms bring surface runoff in contact with the rocks and soils which then distribute their chemical characteristics. Erosion by rivers and streams has deposited alluvium high in natural salts along certain valleys, with these natural salts being returned to the surface waters when moisture, from either precipitation or irrigation, percolates through the alluvial soils.

Soils

The physical features describing the test area are similar to the entire Grand Valley. The soils in the area were classified by the Soil Conservation Service in cooperation with the Colorado Agricultural Experiment Station (31) in 1940. Soil classifications in the project intensive study area are shown in Fig. 7. The soil classification symbols, along with a general description of each symbol, are tabulated in Table 8.

The desert climate of the area has restricted the growth of natural vegetation, thereby causing the soils to be very low in nitrogen content because of the absence of organic matter. The natural inorganic content is high in lime carbonate, gymsum, and sodium, potassium, magnesium, and calcium salts. With the addition of irrigation, some locations have experienced high salt concentrations with a resulting decrease in crop productivity. Although natural phosphate exists in the soils, it becomes available too slowly for use by cultivated crops and a fertilizer application greatly aids yields. Other minor elements such as iron are available except in those areas where drainage is inadequate. The soils in the test area are of relatively recent origin as they contain no definite concentration of lime or clay in the subsoil as could be expected in weathered soils. Some areas in the valley have limited farming use because of poor internal drainage, which results in water logging and salt accumulations.



B_a
B_c
B_d
B_e
C_c
G_k
G_m
P_b
R_a
R_b
R_e
R_f
R_o
R_s
Stub Ditch
Government Highline Canal
Price Ditch
Grand Valley Canal
Mesa County Ditch
Colorado River

Fig. 7. Soil classification map of intensive study area, Area I (31).

Table 8. Soil mapping classification index (31).

Map Symbol	Soil
Bc	Billings silty clay loam, 0 to 2 percent slopes
Ba	Billings silty clay, 0 to 2 percent slopes
Be	Billings silty clay, moderately deep over Green River soil material, 0 to 2 percent slopes
Gm	Green River very fine sandy loam, deep over gravel, 0 to 2 percent slopes
Gk	Green River fine sandy loam, deep over gravel, 0 to 2 percent slopes
Cc	Chipeta-Persayo silty clay loams, 5 to 10 percent slopes
Bd	Billings silty clay loam, 2 to 5 percent slopes
Pb	Persayo-Chipeta silty clay loams, 2 to 5 percent slopes
Rf	Ravola very fine sandy loam, 0 to 2 percent slopes
Re	Ravola loam, 0 to 2 percent slopes
Ro	Riverwash, 0 to 2 percent slopes
Rb	Ravola clay loam, 0 to 2 percent slopes
Rs	Rough gullied land
Ra	Ravola fine sandy loam, 0 to 2 percent slopes

Lying on top of the Mancos shale and below the alluvial soils is a large cobble aquifer extending north from the river to about midway up the test area, as illustrated by Fig. 8. The importance of this aquifer with respect to the drainage problems of the area has been demonstrated by a cooperative study in 1951 between the Colorado Experiment Station in conjunction with the Agricultural Research Service (ARS) (30), which evaluated the feasibility of pump drainage from the aquifer.

Land Use Survey

Evaporation and transpiration from crops, phreatophytes, and other land uses results in a loss of salt-free water to the atmosphere and a deposition of salt in the soil profile. The magnitude of these losses depends on the acreage of each water use. As a part of a valley wide evaluation, the various acreages of land uses in Area I were mapped according to the index presented in Table 9. The acreages for each land use are shown in Table 10 (39). One of the most quoted statements in the literature concerning the Grand Valley is that approximately 30% of the farmable area is unproductive because of the ineffectiveness of the drainage in these areas. Examination of the results presented in Table 10 indicates that 70% of the study area can be classified as irrigable land, however only 52% can be considered productive. The use of the term productive relates to the areas producing cash crops such as corn, beets, grains, orchards, alfalfa, etc. The land use summary for the entire valley will be presented in a later section.

Climate

The mountain ranges in the Upper Colorado River Basin have much more influence on the climate than does the latitude. The movement of air masses is disturbed by the mountain ranges to the extent that the high elevations are wet and cool, whereas the low plateaus and valleys are drier and subject to wide temperature ranges. A common characteristic of the climate in the lower altitudes is hot and dry summers and cold winters. Moist Pacific air masses can move across the basin, but dry polar air and moist tropical air rarely continue all the way across the basin. Movement of both types of air mass is obstructed and deflected by the mountains so that their effects within the basin are weaker and more erratic than in most areas of the country.

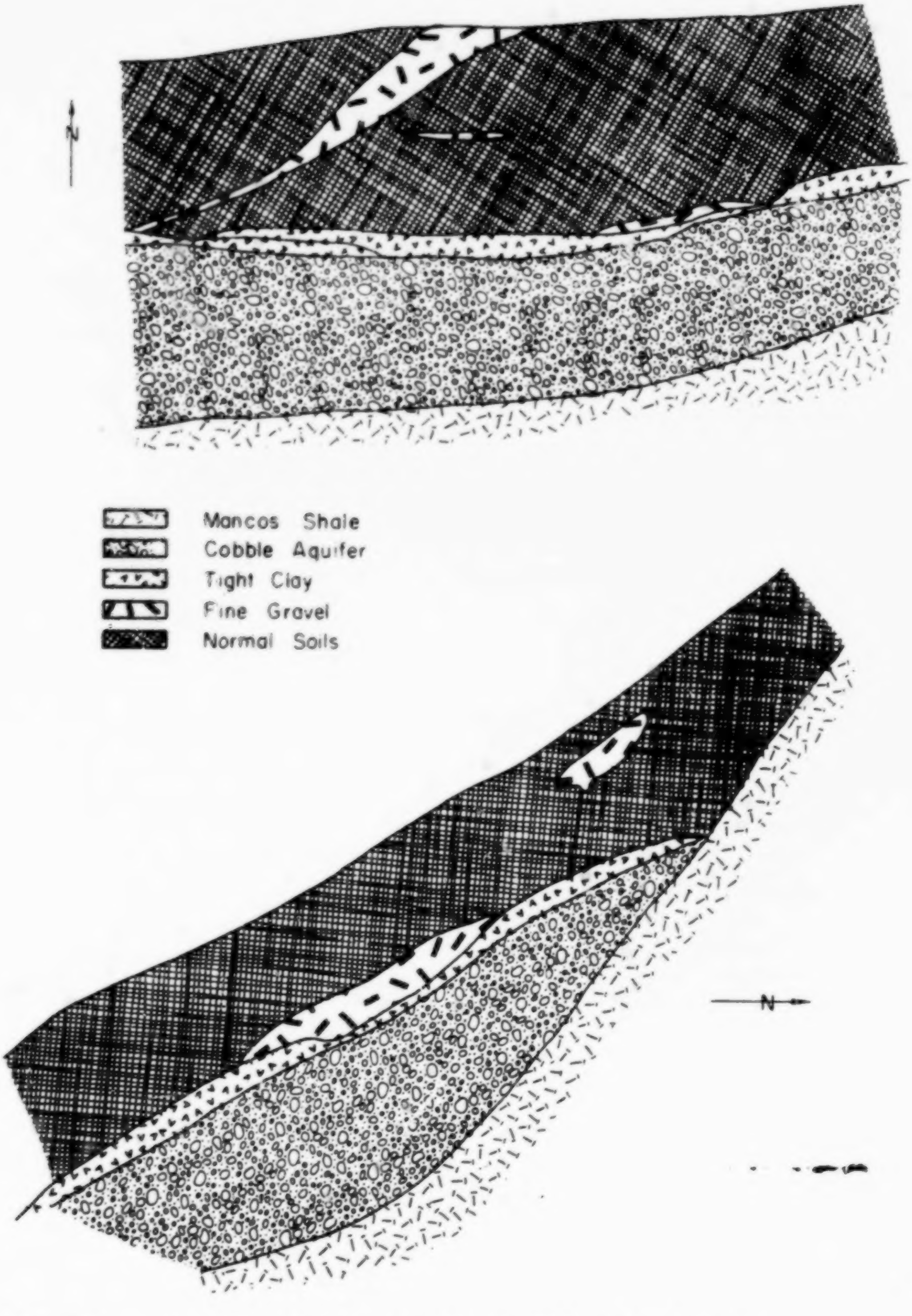

N
Mancos Shale
Cobble Aquifer
Tight Clay
Fine Gravel
Normal Soils
N

Fig. 8. Cross-sections of soil Profiles in Area I.

Table 9. Land use mapping index.

A. Irrigated Cropland

1. Corn
2. Sugar beets
3. Potatoes
4. Peas
5. Tomatoes
6. Truck crop
7. Barley
8. Oats
9. Wheat
10. Alfalfa
11. Native grass hay
12. Cultivated grass and hay
13. Pasture
14. Wetland Pasture
15. Native grass pasture
16. Orchard
17. Idle
18. Other

B. Dry Cropland

1. Alfalfa
2. Wheat
3. Barley
4. Beans
5. Cultivated grasses
6. Fallow
7. Other

C. Other Land Use

1. Farmsteads
2. Residential yards
3. Urban
4. Stock yards

D. Industrial

1. Power Plants
2. Refineries
3. Meat Packing
4. Other

E. Open Water Surfaces

1. Major storage
2. Holding storage
3. Sump ponds
4. Natural ponds

F. Phreatophytes

1. Cottonwood
2. Salt Cedar
3. Willows
4. Rushes or Cattails
5. Greasewood
6. Sagebrush and/or rabbitbrush
7. Wildrose, Squawberry, etc.
8. Grasses and/or Sedges
9. Atriflex

P. Precipitation only

Table 10. Land use in Area I during 1969 (39).

Classification		Acreage		Percent
A1	Corn	487		
A2	Sugar beets	1		
A3	Potatoes	8		
A7	Barley	255		
A8	Oats	14		
A9	Wheat	9		
A10	Alfalfa	545		
A12	Cultivated grass and hay	141		
A13	Pasture	476		
A15	Native grass pasture	387		
A16	Orchard	349		
A17	Idle	559		
A18	Other	6		
	Subtotal		3237	69.9
C1	Farmsteads	258		
C2	Residential yards	61		
C3	Urban	85		
C4	Stockyards	8		
	Subtotal		412	8.9
E4	Open water surfaces	70		
	Subtotal		70	1.5
F1L	Cottonwood (light)	3		
F1H	Cottonwood (heavy)	3		
F2M	Salt cedar (medium)	15		
F2H	Salt cedar (heavy)	253		
F3L	Willows (light)	7		
F3H	Willows (heavy)	63		
F4L	Rushes (light)	1		
F4H	Rushes (heavy)	9		
F5L	Greasewood (light)	67		
F5M	Greasewood (medium)	104		
F5H	Greasewood (heavy)	162		
	Subtotal		687	14.8
Precipitation only		225		
	Subtotal		225	4.9
			4631	100.0

Most of the precipitation to the basin is provided from the Pacific Ocean and the Gulf of Mexico whose shores are 600 and 1000 miles from the center of the basin, respectively. The air masses are forced to high altitudes and lose much of their precipitation before entering the basin. During the period from October to April, Pacific moisture is predominant, but the late spring and summer months receive moisture from the Gulf of Mexico.

The monthly distribution of precipitation and temperature for Grand Junction is shown in Fig. 9 (33). The climate in the area is marked by a wide seasonal range, but sudden or severe weather changes are infrequent due mainly to the high ring of mountains around the valley. This protective topography results in a relatively low annual precipitation of approximately eight inches. The usual occurrence of precipitation during the growing season is in the form of light showers from thunderstorms which develop over the western mountains. The nature of the valley location with typical valley breezes provides some spring and fall frost protection resulting in an average growing season of 190 days from April to October. Although temperatures have ranged to as high as 105°F, the usual summer temperatures range in the middle and low 90's in the daytime to the low 60's at night. Relative humidity is usually low during the growing season, which is common in all of the semi-arid Colorado River Basin.

Irrigation

The system of irrigation most common to the area is surface flooding either by borders or furrows. The study area itself is located in the narrow eastern part of the valley which has a relief of about 50 feet per mile sloping south towards the river. As a result, care is taken to prevent erosion in most cases by irrigation with small streams. Most farms in the area are small and have short run lengths. However, the small irrigation stream allows adequate application. The quantity of water delivered to the farmer is plentiful so the usual practice is to allow self-regulated diversions. Although the method of irrigation is quite similar throughout Grand Valley, there is considerable contrast in land use. The lands at the upper end (eastern) of the valley are largely orchards, which is also the case for the Orchard Mesa lands, which are south of the Colorado River. In contrast to the intensive study area, larger tracts of farm land are located in the western portions of the valley, with many of these lands having good soils which contribute to the production of high yield crops.

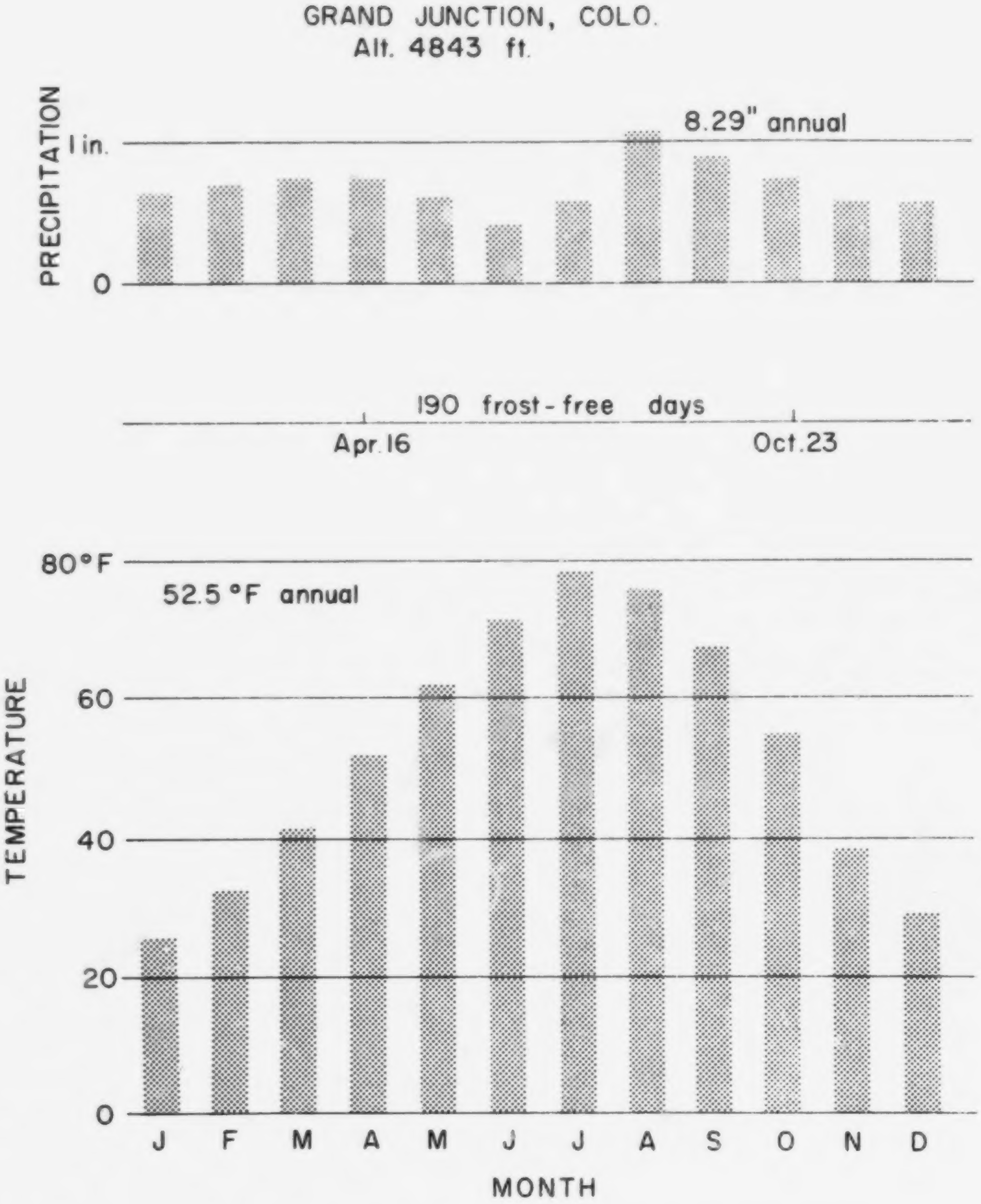


Fig. 9. Normal precipitation and temperature at Grand Junction, Colorado.

SECTION V

SUMMARY OF PREVIOUS RESEARCH

Although the first engineering investigations in the region were conducted to establish the feasibility of developing additional irrigated land, almost every study since has been in some way related to salinity. The early settlers were able to dig shallow fresh water wells, but as irrigation continued, the ground water became too saline for any use. Not until low lying lands began to show signs of high water tables, and older apple orchards began to fail, was the necessity for salinity investigations realized. With the saline soil conditions and natural composition of the soil producing a very low internal drainage capacity, the lapse between first irrigation and the following salinity crisis was about twenty years. This seemingly protracted period would have been greatly reduced if the expansion of the irrigated acreage to the higher regions had been accomplished earlier since the deep percolation from the higher elevations would have added to the drainage requirement in the low lands.

In addition to the drainage and salinity investigations, numerous experiments have been performed to evaluate crop production factors. Many experiments deal exclusively with the agronomic variables. Studies related to the salinity problem in the Grand Valley can be classified according to objective:

(1) Local hydrologic and salinity studies. These studies have been undertaken to define the important hydrologic parameters in the valley so that problem areas can be delineated and alternate solutions examined. Among the investigations in this group are drainage, conveyance seepage, irrigation efficiency, and salinity studies.

(2) Regional hydrologic and salinity studies. When the deleterious impact of an ever-increasing salinity concentration in the basin was realized, the necessity for basin wide planning of salinity control measures was apparent. In order to effectively outline alternatives, extensive reconnaissance level studies were needed to collect data, delineate problem areas, and enumerate alternative actions.

(3) Local salinity control project investigations. After having determined basin salt inputs, the next step in salinity control is to investigate the feasibility of implementing the different courses of action which could be followed to alleviate the problem.

The initiation of the study reported herein marked the beginning of the third type of investigation described above. This section of the report summarizes several of the more significant results obtained from prior studies directed toward the first two objectives listed above.

Local Hydrologic and Salinity Investigations

Drainage

Although many early settlers attested to the seriousness of the drainage problems in the low lying lands of the valley, the conditions were alarming by about 1914. In 1908, D. G. Miller, Senior Drainage Engineer, Bureau of Public Roads and Rural Engineering, initiated an eight-year investigation of the problem covering the irrigated acreage which was served by the Grand Valley Irrigation Company (21). The objective of the study was to point out the contributary causes of the high water table condition in the valley, and to emphasize the necessity of drainage as a remedy. Observations were made throughout the region to determine water quality of soil extracts and ground water, water table elevations, and the effects of high water table conditions.

The early manifestations of injury due to alkalinity in the Grand Valley were first realized when regions in the more mature apple orchards began to fail. Almost invariably, when the older trees died, younger trees would still grow owing to their shallower rooting system. Eventually, even field crops failed, so that finally the land in many cases became unproductive. Soon after the causes of crop failure had been somewhat determined, several farms were selected in the valley where the influence of the Mancos Shale could be studied. At one point in the study, 392 soil samples were taken on which a constituent breakdown was performed on the soil extract. The following was the result of these tests:

Calcium Sulfate	49.5%
Sodium Chloride	13.6%
Sodium Sulfate	10.4%
Magnedium Sulfate	9.7%
Bicarbonate	7.5%
Calcium Chloride	2.1%
Magnesium Chloride	1.6%
Nitrates	2.1%

In addition, water samples were taken from wells that had been drilled to the shale. Also, samples were collected from 1,000 feet of drainage tile connecting six wells drilled into a water bearing strata in the Mancos Shale. Two samples collected May 8, 1914 and March 30, 1915 provided the following results:

	May 8, 1914	March 30, 1915
Sulfuric Acid	13,320 mg/l	10,508 mg/l
Bicarbonic Acid (HCO_3)	632 mg/l	513 mg/l
Nitric Acid	832 mg/l	286 mg/l
Chlorine	490 mg/l	262 mg/l
Calcium	425 mg/l	405 mg/l
Magnesium	873 mg/l	600 mg/l
Sodium	5,904 mg/l	3,901 mg/l
TOTAL	21,671 mg/l	16,475 mg/l

Although the results of these analyses are in a form no longer used, they do provide a useful indication of the mineral quality characteristic of the samples. The realtively high content of nitrates (around 1204 ppm) in some of the samples taken in close proximity to the shale is expected of shale formed from Cretaceous and Tertiary formations.

Examination of wells and piezometers located in the cobble aquifer beneath the soil indicated an upward pressure gradient which could be responsible for areas of high water table. Although the shale beneath the cobble and the impervious clay layer immediately above provide a confining effect, these conditions are not wholly continuous, resulting in areas within a uniform topographic region, which exhibit varying water table heights. The tight nature of the soils was also determined to be the cause of alkalinity problems in areas where the water table was not exceedingly high. For example, some areas showed an alkaline condition when the water table was as much as eight feet below the surface. This was thought to be the result of capillary action in the soils.

The conclusions formulated from this report had much to do with the organization of the Drainage District in 1924. Some of the pertinent results of the 1908-15 study include:

(1) Drainage in the Grand Valley, because of the magnitude of the problem, must be a regional undertaking in three types of drainage. These are (a) relief of the pressure condition existing in the cobble aquifer, (b) interception of canal and lateral seepage and excessive irrigation from irrigated land in the higher parts of the valley, and (c) lateral drainage of the water logged soils in locations where natural drainage is entirely deficient.

(2) The positive hydraulic gradients in the aquifer are significant in numerous locales, but rarely sufficient to bring the water within three to six feet of the surface.

Consequently, high water tables were probably the result of excessive irrigation and seepage.

(3) The analysis of soil samples and ground water samples showed a definite and direct relation between the quantities of nitrate in the samples and the total soluble salts. The percentage of nitrate increases as samples are collected closer to the shale. As a result, the solution of the alkaline problem, irrespective of the source of the nitrates, will eliminate the problem completely. Further, those salts that do remain in the soils can be easily ammended by standard methods.

The results of the investigation showed that a thorough system of drainage based upon a full knowledge and appreciation of underlying conditions would improve the production on about 30% of the irrigated acreage in the valley lying immediately adjacent to the Colorado River. In the early 1940's it was clear that most of the open drains that had been excavated to alleviate the drainage problems in critical areas were ineffective. The effectiveness of drainage depends to a large extent upon the permeability of the soil and the nature of the substrata. In order for drains to reduce the flow of ground water, one of the highly permeable strata must be intercepted. Specifically, for those lands where drainage is the most inadequate, the cobble aquifer should be tapped. In early 1946, an investigation was launched by the Soil Conservation Service (SCS) on the "Willsea" farm west of Grand Junction (8). Piezometer readings indicated the presence of a vertical gradient of 0.48 ft/ft. As an open drain on the north side of the farm had little effect on the problem, it was decided to drill an 8" well into the cobble in order that test pumping could be undertaken for drainage relief. On April 15, 1947 a pump test was conducted by the SCS personnel. Pumping at the rate of 100 gpm had only very local effects, thereby indicating the need for a larger pump and certain well improvements. The possibility of pump drainage was clearly evident and aroused local support for a more detailed study. In 1948, an agreement with the Drainage District and the Soil Conservation District was formalized which initiated a test program in the area. After considerable piezometer analysis and topographic investigations were completed, a well was installed by the Colorado Water Well Company in October 1951 (4). Both the well construction and the drillers' log of the material are shown in Fig. 10. The well was pumped at a rate just exceeding 200 gpm for a period of about four years. The conclusions reached from this study include:

(1) Analysis of the piezometer data indicated that the pump produced a decline in the water table near the well of

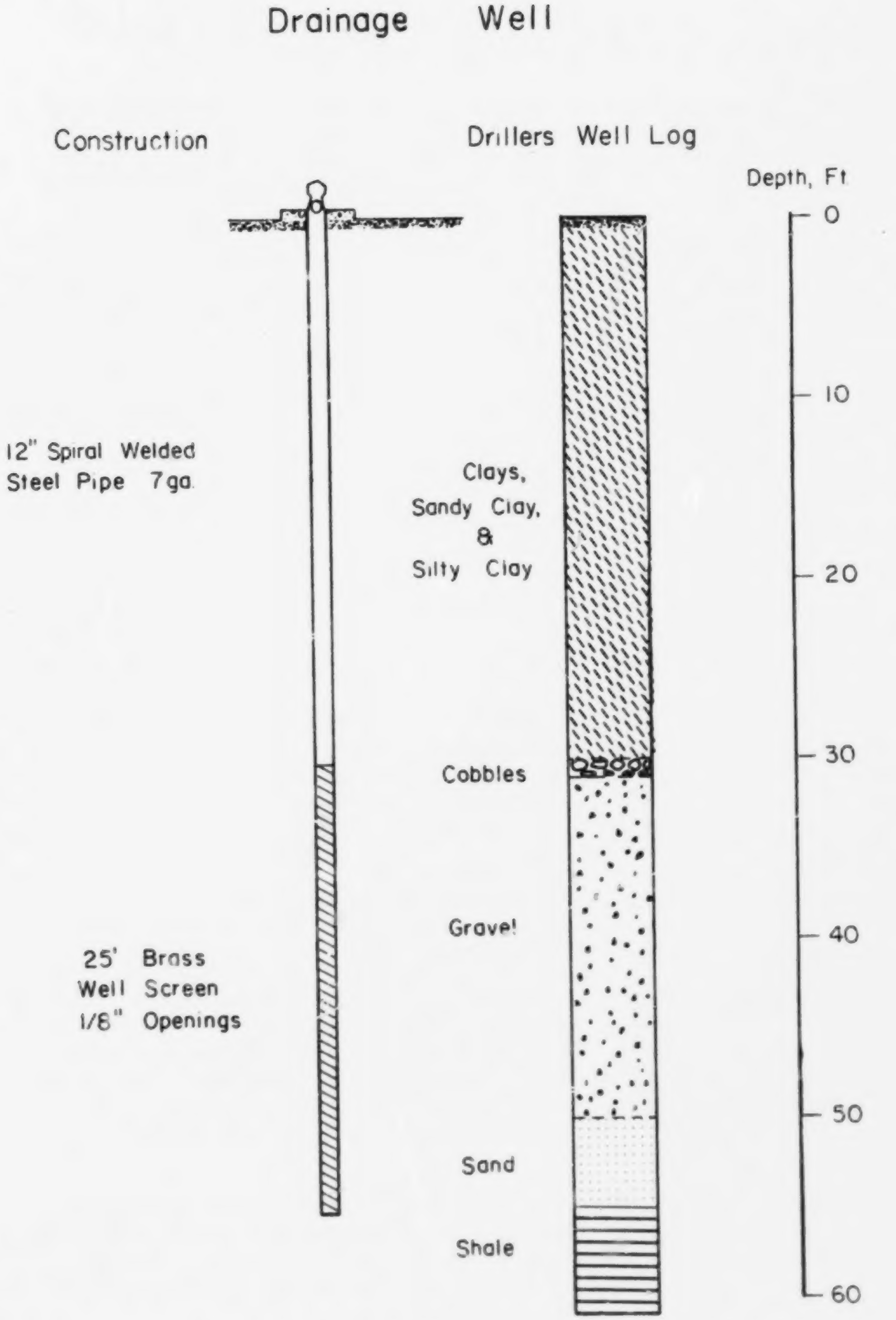

Drainage Well
Construction
Drillers Well Log
Depth, Ft
12" Spiral Welded Steel Pipe 7ga.
25' Brass Well Screen 1/8" Openings
Clays, Sandy Clay, & Silty Clay
Cobbles
Gravel
Sand
Shale
0
10
20
30
40
50
60

Fig. 10. Construction and driller's log of 1951 test well for pump drainage (4).

approximately 0.10 inch per day, which decreased to 0.03 inch per day at a radius of about 1/2 mile.

(2) It was observed that the pumping produced greater and more rapid changes in the aquifer pressure. The fact that the dense clay layer overlying the cobble restricted flow into the cobble from the soil was stated as the reason for the relative slow effect on the water table.

(3) When the pump test was conducted, it was noted that a "hole" in the clay layer existed in the radius of the influence of the pump. It was through this hole that the water above the cobble entered the aquifer. Consequently, a drainage well in any part of the lower valley can be successful only if openings exist in the upper confining stratum which will allow the ground water above to enter the aquifer.

In order to evaluate the effectiveness of natural internal drainage of the area surrounding the well, 27 locations were studied for hydraulic gradient and hydraulic conductivity of the soil strata. The results of the composite tests indicate that only 2.72 acre-inches per month could be handled by natural drainage.

Canal and Lateral Seepage

A complementary investigation to drainage is an evaluation of the sources of the excess ground water. Several studies have been conducted in the valley starting in 1954. The first study was a cooperative enterprise between the Colorado Agricultural Experiment Station and the Agricultural Research Service, U.S.D.A. (4). An eight-mile length of the Grand Valley Main Line Canal was isolated. Both inflow-outflow and seepage meter measurements were taken. The results indicate an average loss rate in the section of about 2 acre-feet per day per mile of canal (0.30 cfd). Later, on July 12, 1955, A. R. Robinson (25) conducted a similar seepage loss investigation on the Government Highline Canal, but little is known of the results. In 1958, Solomonson and Frasier investigated lateral seepage on several 200-foot sections (9). These tests utilized the ponding method of analysis and indicated a loss rate of 0.40 acre-inch/day/mile. Summarizing the results of these studies:

(1) Seepage rates in the canal were significantly higher where the canals were located in the alluvium material. In the shale cuts, the seepage rates were noticeably lower, probably owing to quantities of ground water interception.

(2) Results show that an average of about 5 acre-feet per month per mile of canal through the test area would alone exceed the internal drainage capacity of the soils.

Farm Efficiency

The conclusion has been reached by most investigators in the area that excess applications of irrigation water are the primary cause of the drainage problem in the lower valley. To quantify the magnitude of these contributions, efficiency studies were conducted in 1954 and 1955 by the Colorado Agricultural Experiment Station (4), and by the U.S. Bureau of Reclamation (34). The earlier studies determined that an average of 7.4 acre-inches excess was being applied seasonally, but the farms were located in a small area. In order to provide more reliable data and to provide a basis for extending the results to the valley, the 1955 study involved six new farms between Grand Junction and Fruita, which were supplied by the Government Highline Canal and the Grand Valley Canal. The results of this study indicated a significant amount (as high as 23.7 acre-inches per acre annually) was being applied in addition to consumptive use and leaching requirements. The Bureau of Reclamation study was conducted from 1965 through 1968 on three locally operated farms about 10 miles west of Grand Junction. Careful consideration was given to the parameters affecting the farm efficiencies being attained, as well as the efficiencies that could be attained. The fields ranged in slope from 0.7 to 1.5 percent, and in length of irrigation runs, from 250 to 1252 feet. In addition, all three operators practiced different farming methods to some extent, which gave the investigators an opportunity to observe the effect of farming methods on irrigation efficiency. The summary of the results, given in Table 11, indicated the following general conclusions:

(1) The nature of irrigation in the area in the early part of the season is not conducive to efficient irrigation as the process of "wetting across," or getting the seed bed properly moistened between furrows requires larger furrow streams and long run periods.

(2) Careful observation of efficient water use not only significantly improved yields, but also required less fertilizer.

(3) Control of the Western Cutworm in sugar beet fields by keeping a moist soil is seen to decrease efficiency. Since drainage was not a problem in the area, this practice was common and economical.

Table 11. Overall seasonal irrigation efficiency percentages, weighted by field acres (34).

Year	Data Category	Farm 1	Farm 2	Farm 3	Total
1965	Measured	33.7	40.2		35.6
	No. 1 Attainable[1]	60.5	56.8		59.0
	No. 2 Attainable[2]	68.5	63.9		66.6
	No. 3 Attainable[3]	71.8	72.3		72.1
1966	Measured	28.1	38.7	42.5	34.6
	No. 1 Attainable	57.0	55.8	69.6	60.4
	No. 2 Attainable	67.0	62.7		65.3
	No. 3 Attainable	70.4	68.7		69.2
1967	Measured	24.2	36.3	53.5	32.7
	No. 1 Attainable	57.0	54.9	61.6	58.0
	No. 2 Attainable	66.3	63.1	67.4	65.9
	No. 3 Attainable		67.1		67.1
1968	Measured	28.1	26.2	33.2	29.0
	No. 1 Attainable	55.2	51.6	57.3	54.9
	No. 2 Attainable	65.2	59.8	63.8	63.4
	No. 3 Attainable		66.9		66.9
Avg.	Measured	28.3	33.8	41.3	32.6
	No. 1 Attainable	57.3	56.4	63.1	58.2
	No. 2 Attainable	66.8	64.0	65.5	65.4
	No. 3 Attainable	71.1	68.8		69.3

[1] Attainable water use efficiency with existing system and improved management (no additional labor).

[2] Same as [1] except with additional labor.

[3] Same as [2] except with additional system costs.

(4) Consideration of such factors as leaching and salt loads during critical growth periods, as well as soil tilth, not only improved yields, but also affected irrigation efficiency.

Irrigation Methods

Because the saline soils have always been a problem, attempts have been made to study certain alternative irrigation methods to determine their effect upon crop production. Sprinkler irrigation has usually been immediately abandoned because of the crusting characteristics of the soil, as well as the cost of such systems. During the 1954 irrigation season, personnel of the Colorado Agricultural Experiment Station conducted infiltration studies. The results are listed in Table 12 (5). The reported infiltration rates are averages over a time period of 10 hours, or more. Since infiltration rate curves are not available for these same soils, interpretation of the reported data is quite difficult. For example, a low infiltration rate listed in Table 12 may only indicate that water was being applied at a rate less than the infiltration capacity of the soil. Also, the net irrigation (inflow minus outflow) does not show the influence of furrow stream size upon infiltration characteristics. In general, at least two inches of water could be infiltrated into the soil in a 12-hour period.

Salinity Constituents

The high clay and silt content of the local soils is greatly affected by the types of salts present. It has been established that calcium salts, for example, although not desirable in large quantities, tend to coagulate dispersed soil particles, thereby increasing the permeability of the soil and enhancing the leaching process. In contrast, sodium disperses soil particles, thereby reducing the permeability, which further reduces the drainage capacity of the soil. Consequently, it is necessary to evaluate the amount of sodium present in the soil to make judgments on drainage design and the potential for alleviating the general detrimental effects of the salts. The studies reported earlier by the Colorado Agricultural Experiment Station considered this problem by evaluating the "exchangeable sodium percentage." Table 13 summarizes portions of the 1952-55 studies (30). In a later section, this analysis will be extended to river water, soils, ground water, and irrigation return flows to determine the net contribution by the whole valley.

Table 12. Results of 1954 infiltration study (4).

Date[2]	North Repl.			Middle Repl.			South Repl.		
	Net Irrig. in.[3]	Time hr.	Rate[1] in./hr.	Net Irrig. Inches	Time hr.	Rate[1] in./hr.	Net Irrig. Inches	Time hr.	Rate[1] in./hr.
	SUGAR BEETS, Plots (3,7,22)(8,10,25)(16,29,32)								
6-14,15,16	3.26	10	0.326	3.28	10	0.328	3.56	10	0.356
7-8,9 10	2.10	11	0.191	3.03	11.25	0.269	3.04	11	0.276
7-23,24 25	2.59	11	0.235	2.08	11	0.189	3.15	18	0.175
8-3,4,5	2.69	11	0.245	2.44	10	0.244	1.45	19	0.076
8-23,24,25	3.04	12	0.253	3.20	12	0.266	3.05	12	0.254
9-20,21,22	4.23	12	0.353	3.72	13	0.286	2.99	14	0.214
	CORN, Plots (2,4,20)(9,24,27)(14,30,33)								
5-17,18	3.39	34	0.099	6.97	45	0.154	6.09	44	0.138
6-22,23,24	2.80	11	0.254	3.04	11	0.276	3.77	11	0.343
7-12,14,15	2.78	12	0.232	2.03	23	0.088	1.64	12	0.136
7-26,27,28	2.53	17	0.148	2.14	16	0.134	2.55	19	0.134
	BARLEY, Plots (5,21)(12,26)(18,31)								
6-4,5,7	4.11	23.5	0.175	0.45	22	0.020	0.82	13	0.063
6-25,26,27	3.24	12	0.270	2.36	11	0.21	2.43	17	0.142
7-29,30,31	4.08	12	0.340	3.16	12	0.263	4.24	13	0.326
	ALFALFA, Plots (1,6,19)(11,13,23)(15,17,28)								
5-27,28									
6-3	1.79	16	0.111	5.60	23	0.243	3.47	23	0.151
6-28,29,30	6.12	23	0.266	5.20	22	0.236	4.76	23	0.206
7-19,20,21	6.07	23	0.264	5.17	23	0.225	4.72	23	0.205

[1] Infiltration rate used is the net irrigation divided by the total time.

[2] Records up to June are in general of no value because irrigation was not done by replicates.

[3] Inflow minus outflow.

Table 13. Results of 1952-1955 field leaching study showing effect on exchangeable sodium percentage.

Treat-ment[1]	Sampling Date[2]	EXCHANGEABLE SODIUM PERCENTAGE Soil depth - inches 0-9	9-18	18-30	30-48	48-60	60-72	72-84	84-96	Alfalfa yield Tons/Ac
W_1G_1	1	11.46	10.74	10.69	11.01	---	---	---	---	---
	2	5.23	6.61	12.38	15.98	---	---	---	---	---
	3	6.80	11.33	19.54	25.38	---	---	---	---	4.01
	4	6.21	9.32	16.28	18.74	23.89	23.66	21.10	17.95	3.44
	5	6.44	10.98	12.60	16.59	18.33	---	---	---	2.19
W_1G_2	1	7.47	13.84	23.30	25.67	---	---	---	---	---
	2	4.61	6.21	10.67	16.89	---	---	---	---	---
	3	5.77	8.81	14.09	19.50	---	---	---	---	4.72
	4	5.01	8.35	15.61	21.84	24.11	21.54	22.63	18.49	4.18
	5	5.96	9.56	18.00	24.07	22.53	---	---	---	2.73
W_2G_1	1	8.25	9.95	14.08	18.80	---	---	---	---	---
	2	3.40	4.69	4.89	8.11	---	---	---	---	---
	3	4.86	6.09	6.89	11.00	---	---	---	---	5.30
	4	5.37	5.29	6.76	11.72	17.72	21.35	19.03	19.59	5.01
	5	5.75	6.53	9.76	15.81	23.25	---	---	---	3.18
W_2G_2	1	9.45	13.69	18.52	18.49	---	---	---	---	---
	2	3.76	4.48	5.06	8.94	---	---	---	---	---
	3	5.31	4.73	6.65	15.59	---	---	---	---	5.00
	4	5.36	5.22	6.01	15.60	15.18	21.95	21.01	19.18	5.01
	5	6.46	6.78	8.68	19.73	23.35	---	---	---	3.00
W_1 (Mean, all plots)	1	9.47	12.29	17.00	18.34	---	---	---	---	---
	2	4.92	6.41	11.53	16.44	---	---	---	---	---
	3	6.29	10.07	16.81	22.44	---	---	---	---	4.37
	4	5.61	8.84	15.95	20.29	24.00	22.60	21.87	18.22	3.81
	5	6.20	10.27	15.30	20.33	20.43	---	---	---	2.46
W_2 (Mean, all plots)	1	8.85	11.82	16.30	18.65	---	---	---	---	---
	2	3.58	4.59	4.98	8.53	---	---	---	---	---
	3	5.09	5.41	6.77	13.30	---	---	---	---	5.15
	4	5.36	5.26	6.39	13.66	16.45	21.65	20.02	19.39	5.01
	5	6.11	6.66	9.22	17.77	23.30	---	---	---	3.09

[1] Reclamation treatments, 1952-53

W_1 - Leaching with 2 acre-feet of water/acre

W_2 - Leaching with 6 acre-feet of water/acre

G_1 - No gypsum

G_2 - Gypsum, 4 tons/acre

[2] Sampling dates:

1 - Before reclamation, May, 1952
2 - After reclamation, August, 1953
3 - After 1 crop year, September, 1954
4 - After 2 crop years, September, 1955
5 - After 3 crop years, October, 1956

Regional Hydrologic and Salinity Studies

The increasing salinity problem in the Colorado River Basin has necessitated the collection and analysis of data on water and salt flows in order to evaluate the contributions from various sources. Although several interested governmental agencies have conducted short term studies in the basin, the primary source of data is the stream monitoring system of the U.S. Geological Survey. One of the most comprehensive efforts to summarize and analyze these data was made by Iorns, Hembree, and Oakland (16) for the period between 1914 and 1957 and adjusted to the 1957 conditions. The study was inclusive of the entire Upper Colorado River Basin, but for the purposes of this report only the section dealing with the Grand Valley area has been extracted. Because of the location of the exiting gaging station being below the confluence with the Delores River, some of the data are not uniquely representative of the Grand Valley.

Some of the results of this study provide an interesting overview of the basin-wide implications caused by water use in the Grand Valley. An extraction of part of the data is shown schematically in Fig. 11, showing the fraction of water and salt that flow in the Grand Valley in proportion to the water and salt flows at Lee's Ferry, Arizona. The effect caused by water resource development in the basin upstream from the Grand Valley was shown to be an increase from 178 to 592 ppm in the Gunnison River Basin and from 272-387 ppm above Grand Valley along the main stream. The net effects of man's activities through the Grand Valley were determined to be a salinity increase from 256 to 547 ppm. The total salt loading to the Colorado River from the Grand Valley averaged about 750,000 tons during the period, although when adjusted to the 1957 conditions, the value was set at 440,600 tons. In terms of tonnage contribution per acre, the figure would be between 5 or 6 and 8 tons per acre, depending on the time period used.

The wide fluctuation in salt pickup through the Grand Valley is shown in the report by Iorns, et. al to be related to the river discharge. For example, during the period from about 1930 to 1942, the average was 860,000 tons pickup per year, in 1943 to 1951 the average pickup was 745,000 tons/year, and in the 1951-1957 period the addition was only 490,000 tons/year. The significance of this variation in salt pickup is that during each of these time periods, the annual river discharge was decreasing, which would indicate that during water short years the farm efficiency increased or ground water storage increased, thereby resulting in dramatic salinity control circumstances.

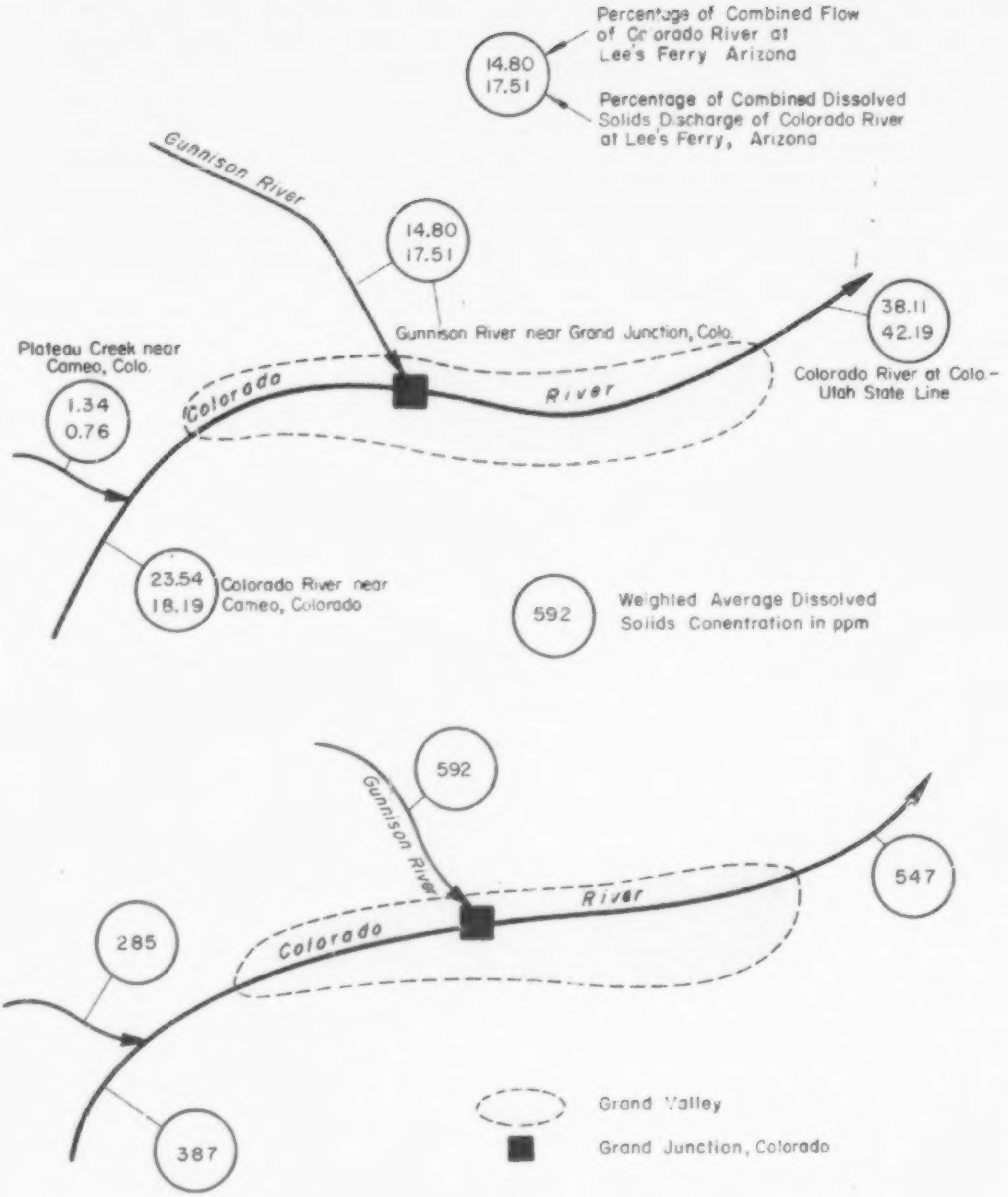

14.80
17.51
Percentage of Combined Flow of Colorado River at Lee's Ferry Arizona
Percentage of Combined Dissolved Solids Discharge of Colorado River at Lee's Ferry, Arizona
Gunnison River
14.80
17.51
Gunnison River near Grand Junction, Colo.
38.11
42.19
Colorado River at Colo.-Utah State Line
Plateau Creek near Cameo, Colo.
1.34
0.76
Colorado
River
23.54
18.19
Colorado River near Cameo, Colorado
592
Weighted Average Dissolved Solids Conentration in ppm
592
Gunnison River
547
River
285
Colorado
387
Grand Valley
Grand Junction, Colorado

Fig. 11. Water and salt flow diagram in the Grand Valley based on 1914-57 data adjusted to 1957 conditions.

The 1963-1967 water years were selected by the Colorado River Board of California (7) in conjunction with various governmental agencies to appraise the salinity sources in the basin and to evaluate the future impact of water resource developments on mineral water quality. The results pertaining to the Grand Valley in particular indicated the salt pickup to be about 8 tons per acre per year, which is the results Hyatt (14) established for the 1963-1968 years (Fig. 12). Both of these references are useful data sources for examination of the Upper Colorado River System. Also, both studies utilized salinity data collected by the Federal Water Pollution Control Administration (now the U.S. Environmental Protection Agency).

Two additional references, not directly related to salinity studies but helpful sources of information, are listed as references (7) and (18).

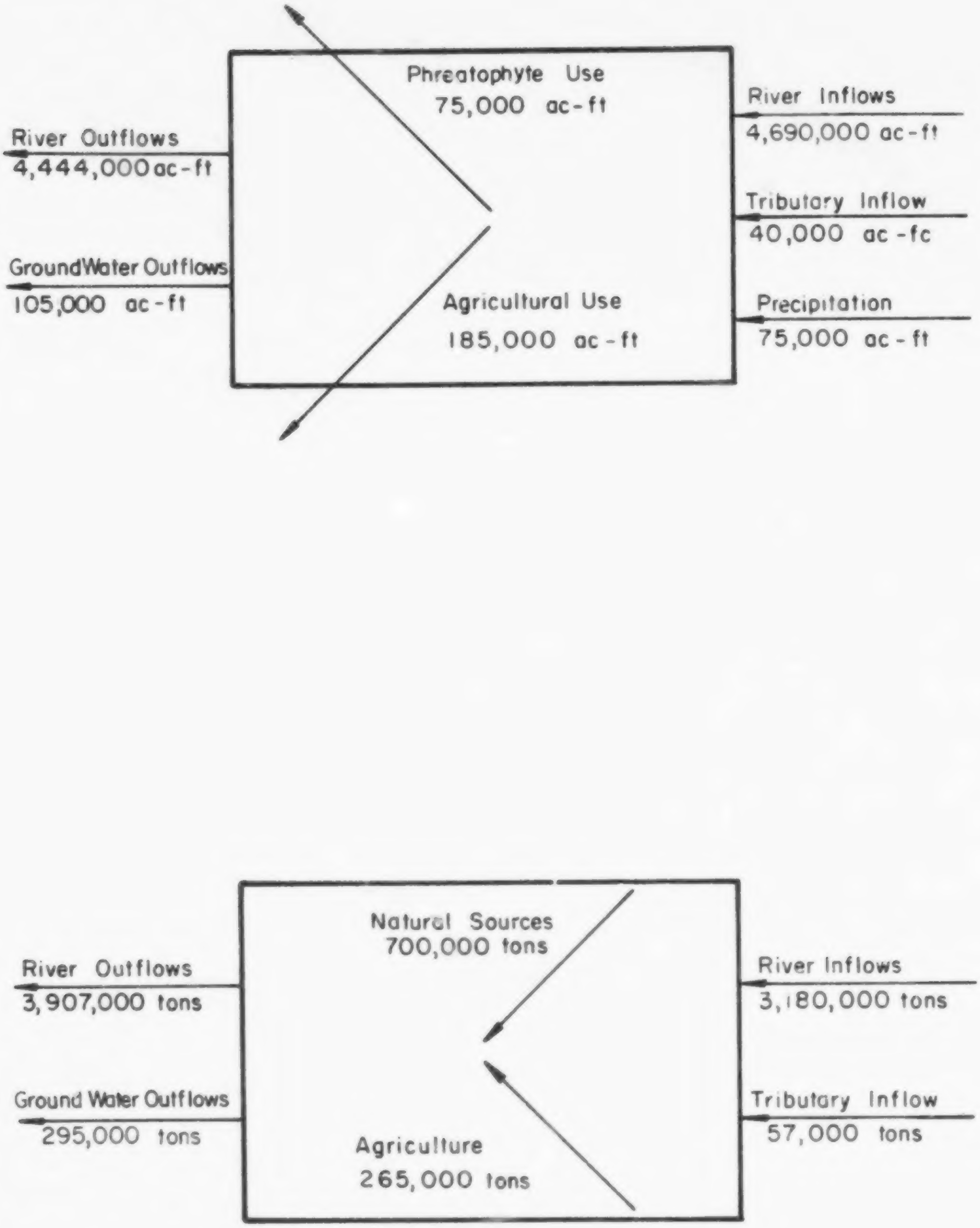

Phreatophyte Use
75,000 ac-ft
River Outflows
4,444,000 ac-ft
River Inflows
4,690,000 ac-ft
Tributary Inflow
40,000 ac -fc
GroundWater Outflows
105,000 ac-ft
Agricultural Use
185,000 ac-ft
Precipitation
75,000 ac-ft
Natural Sources
700,000 tons
River Outflows
3,907,000 tons
River Inflows
3,180,000 tons
Ground Water Outflows
295,000 tons
Tributary Inflow
57,000 tons
Agriculture
265,000 tons

Fig. 12. Schematic water and salt budget for the Grand Valley during 1963-64 water years (14).

SECTION VI

GRAND VALLEY HYDRO-SALINITY SYSTEM

The preparation of water and salt budgets requires a quantitative description of the pertinent segments of the respective flow systems. Even though the emphasis of this study is in the small intensive study area, Area I, the examination of the system on a valley wide scale allows a better understanding of the regional characteristics and thus permits a more reasonable basis for generating conclusions.

In undertaking the Grand Valley Salinity Control Demonstration Project, one of the first tasks was to conceptualize a hydro-salinity model of the intensive study area. This model had to have sufficient sensitivity to detect the effects of canal lining upon the salt pickup reaching the Colorado River. Then, the model could be used to design the field data collection system. Finally, the model could be used to extrapolate results from the intensive study area to the entire Grand Valley.

A difficulty often encountered while preparing water and salt budgets is the variability in the accuracy and reliability with which the hydrologic and salinity parameters are measured. Usually, the measurement precision varies with the scope of the research and the area of the study. The intensive study area on this project has been observed in great detail as will be shown in a later section, but the description of the valley itself is based primarily on the work of others and thus is more generalized. Because of these circumstances, it is helpful in the understanding of investigation results if the techniques employed in computing the budgets and the simplifying assumptions which are made are examined.

Since the hydrologic system is difficult to monitor and predict, it is impractical to expect their models to operate without applying some adjustments in order that all components will be in balance. In short, the budgeting procedure is usually the adjustment of the segments in the water and salt flows according to a weighting of the most reliable data until all parameters represent the closest approximation of the area that can be achieved with the input data being used. The vast and lengthy computation procedure of calculating budgets is facilitated by a mathematical model programmed for a digital computer. A complete listing and explanation of its operation has been previously reported (38). For the purposes of this report, the more important aspects will be extracted for discussion. A schematic diagram of a general hydro-salinity model is shown in Fig. 13.

The hydro-salinity system of the Grand Valley can be divided into four general areas:

(1) Inflows. Inflows represent the total water potentially available for use within the area and the dissolved minerals carried by this water. Included in this group are river, tributary, and ground water inflows, importations, and precipitation.

(2) Cropland diversions. From the available supply of water (river inflows) coming into the valley, diversions are made into canals. From the main supply canals, small turnout structures are used to divert the water into small lateral ditches which lead to the fields.

(3) Ground water. Water that is applied to the land in the form of precipitation or irrigation may be either transpired by the crops or lost through deep percolation into the ground water flow system.

(4) Outflows. Once having been used, the water returns to the river system or is lost to the atmosphere through evapotranspiration. Numerous routes are taken by the water to reach the river including surface drainage and ground water return flows.

In the following sections, the aspects of these divisions are explored.

Inflows

River Inflows

The exclusive sources of irrigation water in the Grand Valley are the Colorado and Gunnison Rivers. Together, the two rivers represent an annual average combined flow of 6500 cfs from which large check type structures are used to divert the water into the principal supply canals. Owing to the increased development of the water resources in the Upper Colorado River Basin, the discharges in the rivers in the Grand Valley region are highly affected both in terms of volume and flow rate by transbasin diversions to Colorado's Frontal Range, reservoirs, power development and irrigation. The Colorado River, at the east entrance to the valley,

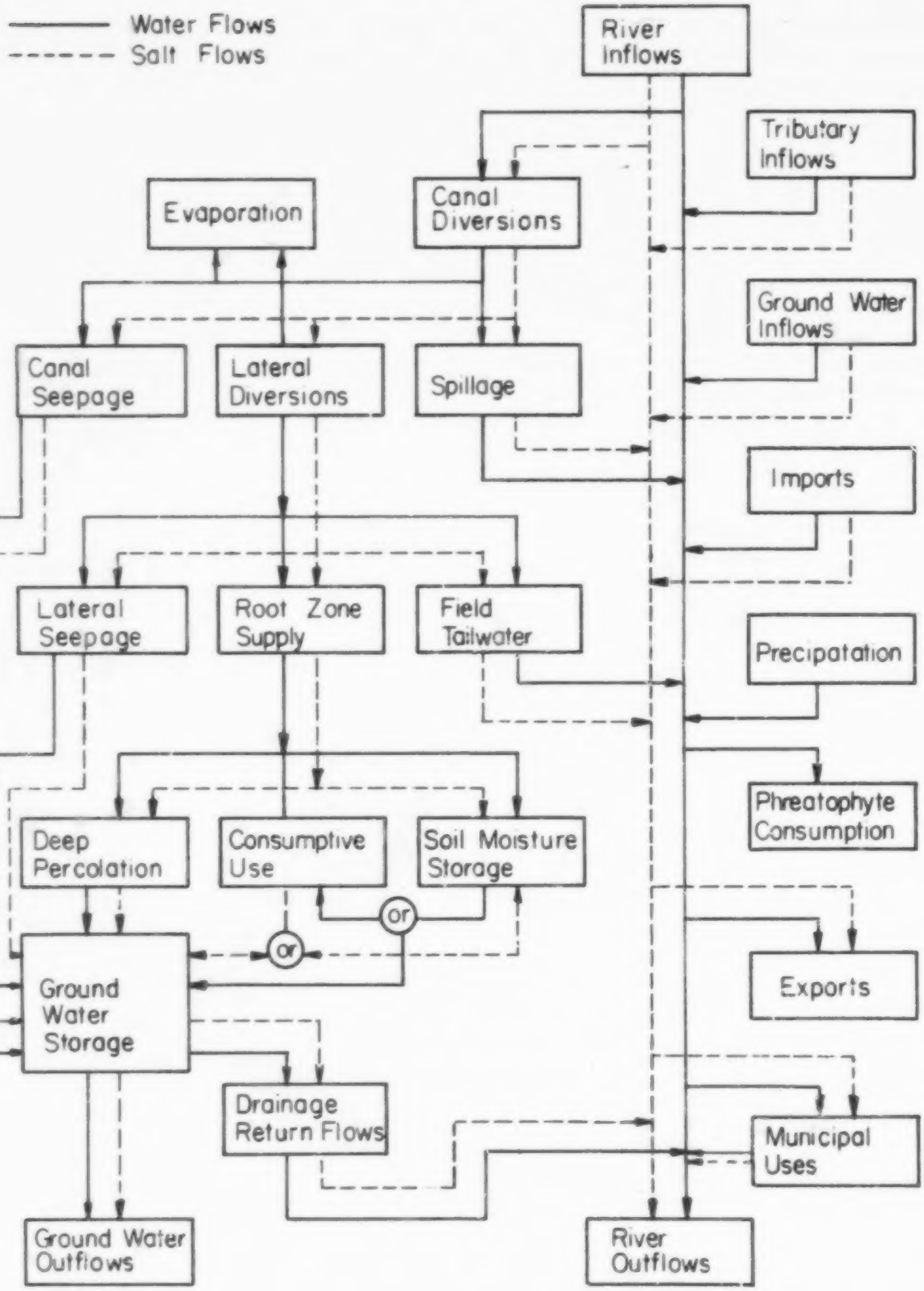

Water Flows
Salt Flows
River Inflows
Tributary Inflows
Canal Diversions
Evaporation
Ground Water Inflows
Canal Seepage
Lateral Diversions
Spillage
Imports
Lateral Seepage
Root Zone Supply
Field Tailwater
Precipatation
Phreatophyte Consumption
Deep Percolation
Consumptive Use
Soil Moisture Storage
or
or
Exports
Ground Water Storage
Drainage Return Flows
Municipal Uses
Ground Water Outflows
River Outflows

Fig. 13. Schematic diagram of generalized hydro-salinity model.

drains an area of about 8,050 square miles resulting in an annual average discharge of about 4000 cfs. Dissolved solids concentrations at the station, "Colorado River near Cameo," range from 150 to 1000 ppm, with the annual flow-weighted mean between 300 and 400 ppm. Salinity levels fluctuate seasonally with peak concentrations occurring during the low flow months of the year, usually December and January. The river at this point also carries large sediment loads, especially during the high flow periods in the spring, which aids irrigation in the valley by reducing intake rates during the early growing season when smaller irrigations suffice. The effect of development upstream of Grand Valley is clearly noticeable, as has been previously indicated. A large part of these conditions are related to the approximately 190,000 irrigated acres which deplete about 190,000 acre-feet of water annually from the river system (7). The Gunnison River Basin, while about the same size, uses about 350,000 acre-feet annually on about 270,000 acres. The resulting annual flow at Grand Valley is reduced to about 2500 cfs, but contains between 500 and 600 ppm of salts. The variation in salinity of waters diverted for irrigation range from 150 to 3,000 ppm, with a few measurements of 6,000 ppm. These higher values of salinity usually occur in the Fall months for waters diverted from the Gunnison River. Also, the waters diverted from the Gunnison River are used in the Redlands area, which is located south of the Colorado River and west of Grand Junction. The alluvial soils in this area facilitate drainage so that local salinity damage is not prevalent. The lands north of the Colorado River use irrigation waters having a maximum salinity of 1000 ppm.

Tributary Inflows

Tributary inflows, which are the ungaged water resulting from precipitation on the adjacent area in the valley, actually account for only a minor portion of the water passing through Grand Valley. Aside from the 60,000 acre-feet added by Plateau Creek, the estimated yield from the surrounding watershed is only about 55,000 acre-feet (7), (14), (16). As noted earlier, the precipitation averages about 8 to 9 inches per year and the intensity is usually low enough to allow the soils to store most of the water. The area is marked by natural washes, evidence that some periods of tributary inflows occur, but for the majority of the time, the flows in these washes are field tailwater and drainage return flows.

Imports

Importation of water from nearby mountain watersheds currently supplies the bulk of domestic demands in the valley although new treatment facilities have been built to use water from the Colorado River. In addition, several deep wells are used to supply some domestic and commercial water demands. None of this water is used for irrigation as a rule because of the abundance of river water.

Ground Water Inflows

Ground water inflows to the valley are essentially impossible to measure, but should be accounted for in the water and salt budgets. Hyatt (14), using an electronic analog computer system model of the Grand Valley, indicated little or no ground water inflows to the region. His conclusion seemed well justified as both the rivers enter the valley through rocky mountainous channels.

Cropland Diversions

Canal Diversions

The source of the irrigation water supply is the diversion into canals by means of check-type diversion dams. Distribution of the canal flows occurs in four ways: (1) diversions into the farm lateral system; (2) seepage; (3) spillage into wasteways; and (4) evaporation.

By using the natural washes as wasteways, the individual canal companies maintain regulation points along the system where control of downstream flows can be made. This practice has the advantage of affording ready compensation for drastic events such as irrigation cutbacks due to foul weather or increased demands by periods of warmer weather. Even though this practice is not a desirable water management alternative, the long length between canal headworks and the end of the distribution system, along with the abundance of water, make spillage the most employed regulation tool in Grand Valley. One situation does exist where spillage is used to supply another segment of the system. The Grand Valley Canal spills water into what is known as Lewis Wash, in the study area, which is then diverted by the Mesa County Ditch. A noticeable consequence of this particular operation is the poorer quality of irrigation water being used by irrigators served by the Mesa County Ditch resulting from mixing the spillage with the drainage waters in Lewis Wash. The salinity being added to the spilled water throughout the valley is difficult to determine, but in the course back to the river system, evaporation and phreatophyte consumption further concentrate existing salt concentrations.

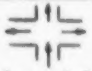
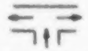
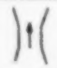
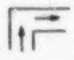
Seepage from the conveyance channels enters the ground water basin directly and, in the Grand Valley, these flows complicate an already serious drainage problem. Most estimates of the magnitude of the seepage losses range in the neighborhood of 20%, but considerable variability has been noted. For example, studies by different researchers have indicated that seepage along canal sections built through the alluvial soil are much higher than those in which the channel had been cut through the shale formations.

Lateral Diversions

The term lateral as used in this text refers to those small conveyance channels that deliver water from the company operated canals to the farmers' fields. These small conveyance channels usually carry flows less than 5 cfs, and range in size up to 4 or 5 feet of wetted perimeter. During the early part of this project, the lateral system in the Grand Valley was assumed to have about the same impact on the overall system as did the canals. Later efforts showed that the lateral system in the valley is so immense in total length as compared with the canal system that this assumption was wrong. In order to demonstrate the extensive magnitude of the lateral distribution, studies were conducted by project personnel to establish the extensiveness of the system. In each different region of Grand Valley, sections (640 acres) were surveyed to establish the lengths of lined and unlined laterals, as well as determining the need for additional water control structures, so that analysis regarding the effect of laterals upon salinity control could be made. A summary of this work has been included in Table 14 at this point in the report, even though a more detailed discussion will follow in a later section of this report.

In a manner similar to the distribution of canal discharges, lateral diversions may be divided into four classes: (1) diversions reaching the crop root zone; (2) flows that are allowed to run off the ends of the fields during irrigation, otherwise known as field tailwater; (3) seepage losses; and (4) evaporation from the water surfaces. The nature of irrigation practices in the region is not conducive to efficient handling of water in the laterals due to their tremendous lengths. Other factors influencing water management methods include the slope of the land, which is about 50 feet per mile in some places, and the inexpensive water supply.

Table 14. Results of lateral survey.

Location		Lateral Lengths (ft)				Ave Discharge (cfs)	 (each)	 (each)	 (each)*	 (each)
Township	Sec	Farm Unlined	Farm Lined	Supply Unlined	Supply Lined					
T1S, R1E	2	10,560	500	7,930	1,060	0.75		7	24	1
	3	36,990	4,350	9,074	7,950	2.0	4	23	72	
	4	4,600			1,060	0.75		3	11	
	9	4,570		7,500	480	1.60		3	14	
	10	31,840	10,060	26,370	4,780	1.50	1	37	106	1
	11	4,920			680	0.5	2	3	11	
	15	36,040	6,570	23,330	6,040	2.50	4	42	107	1
	16	29,020	8,160	8,340	6,960	1.00	5	32	82	3
	17	34,620	1,520	28,310		2.50		36	87	1
	20	25,750	640	7,470	1,600	1.00	2	22	47	
	28	48,640	9,970	15,640	4,880	1.25	7	28	74	
T1S, R2E	9	22,280	12,300	5,020	14,410	0.75	5	18	61	
T1S, R1W	7	12,830	8,450	6,440	1,920	0.50	1	11	36	
T11S, R101W	22	22,700	2,290	9,130	7,500	0.75	3	5	34	
T2N, R2W	35	15,580	18,900	7,130	14,260	2.5	3	12	33	11
T1N, R2W	3	4,750	4,230	15,310	13,200	2.5	2	12	31	
	11	3,700	12,140	23,760	16,370	2.5		8	26	
	15	28,510	1,320	30,360	5,540	2.0	2	21	52	
	23	17,210	3,780	3,960	21,500	2.5	3	19	47	

*Measuring flume

Numerous instances exist where the water in laterals flows continuously, with the water not used for irrigation being dumped into the surface drainage system. A preliminary sampling of these discharges indicated some salt pickup from the soil surfaces, as well as concentrating the salt due to evaporation from water surfaces.

Root Zone Water

The purpose of irrigation is to supply the crop root zone with sufficient water to meet the evapotranspiration demands. During the process of crop water use, the dissolved minerals in the water are isolated, resulting in accumulations occurring in the root zone. This situation necessitates a leaching of these salts by an additional quantity of water. There are often difficulties in irrigating farm lands because of the relative effects of water on the plants. For example, when insufficient moisture is provided during critical growth periods, the reduction in yield may be enormous. In most situations, a small excess produced very little damage, resulting in a tendency to over-irrigate. The consequences of over-irrigation are unnecessary fertilizer leaching, high water tables and drainage requirements, and large salt additions to the river systems.

Water moving into the root zone is either lost to the atmosphere through evapotranspiration, or lost through deep percolation below the root zone, or it may be stored within the root zone. The delineation of these flows by measurement is extremely difficult and impractical on a large scale. Consequently, the procedure most often used is empirical computational methods.

Numerous methods of estimating evapotranspiration have been developed for agricultural lands. Probably the two most adaptable methods for the semi-arid western regions are the Blaney-Criddle method (3) and the Jensen-Haise method (17). The Blaney-Criddle method involves the determination of consumptive use as a function of mean monthly temperature and the percentage of daylight hours occurring during the month. The general equation can be expressed as,

$$U = (t \cdot p/100) \cdot (K_c \cdot K_t) \cdot (A)/12 \quad \ldots\ldots\ldots\ldots(1)$$

Where U is the water use in acre-feet, t is the mean monthly temperature in degrees Fahrenheit, p is the yearly daylight hour percentage occurring during a month, K_c is the crop growth stage coefficient determined experimentally for each individual crop, A is the acreage of a particular crop or phreatophyte, and K_t is a climatic coefficient expressed as,

$$K_t = 0.0173 \cdot t - 0.314 \quad \ldots\ldots\ldots\ldots(2)$$

The Jensen-Haise method was formulated from the evaluation of about 3,000 published and unpublished reports on short period measurements of evapotranspiration using soil sampling procedures during a 35-year interval in the western USA. The resulting equation is,

$$ET = K_c \, E_{tp} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

in which ET is the evpotranspiration, K_c is a crop coefficient much like the Blaney-Criddle K_c value, and E_{tp} is the potential evapotranspiration in a well watered soil in a semi-arid area. The value of E_{tp} is computed by a relationship between air temperature and solar radiation,

$$E_{tp} = (0.014t - 0.37) \cdot R_s \quad \ldots\ldots.(4)$$

where t is the temperature in degrees Fahrenheit and R_s is the solar radiation in Langleys.

In order to determine the magnitude of deep percolation losses and root zone storage, some simplifying assumptions must be made. Since vegetation is only capable of transpiring at its potential rate when soil moisture storage is adequate, an adjustment based on the storage and irrigation supply whenever insufficient water is available must be made to the potential value. The measured values of canal and lateral diversions do not reflect the application on each field or each crop and so the assumption has been made that the irrigation is made uniformly over the cropland. Thus, the water used from the root zone would only involve crop requirements, and phreatophyte use was assumed to be from the moisture below the water tables. Evaluation of reported crop and soil characteristics in the area can be made to determine root zone depths and soil moisture storage capacity as they change with time (3, 11, 17, 24, 31). Once these parameters have been established for an area, a budget of root zone water can be made. The calculated total potential consumptive use is first compared with the total water added to the root zone from irrigation and precipitation. Three alternatives are assumed:

(1) If the supply to the root zone is less than the potential demand, but ample water is stored within the root zone to meet the deficit, then the use would be equal to the potential demand. Since the usual budgeting procedure is carried out on a monthly time interval, the next period of study would have an unused root zone storage that would be filled or supplemented with that period's supply. It has

been assumed that whenever a deficit in root zone storage exists, no water is lost to deep percolation.

(2) If the sum of the supply and the available storage is less than the potential demand, the actual use is assumed to be the total quantity available. A term called consumptive use deficit is defined as the difference between potential demand and the actual use. Again, there would be no deep percolation loss.

(3) If the supply to the root zone is sufficient to meet the potential demand, the actual use would equal this demand. If the excess is sufficient to refill the soil moisture storage, the deep percolation loss would be that amount of water greater than is necessary to refill the soil moisture storage to field capacity.

An illustrative flow chart of this routine is shown in Fig. 14.

Ground Water

The discussion of ground water in this section is limited to the area below the water table as the root zone discussion of the preceding section involved the region above the water table. Ground water recharge in the agricultural region is comprised of canal and lateral seepage as well as deep percolation of applied irrigation water. The hydraulic gradient resulting from the recharge causes the movement of water towards and into the river system.

Ground water discharges involve two phases: (1) drainage interception; and (2) subsurface outflows. Since the water table is often intersected by the drainage system, these flows are easily measured by flow measuring devices located in these drains. The subsurface outflows cannot be measured, but with water table elevation data throughout the area, along with hydraulic conductivity measurements in the various subsurface strata, these flows can be reasonably computed. Even though considerable effort can be made to monitor the pertinent subsurface variables, the data usually obtained do not warrant a non-steady state analysis unless a ground water study is the specific objective of a project. For the purposes of this study, Darcy's steady state equation has been used (19):

$$Q = AK(dh/dx) \quad ....(5)$$

in which Q is the discharge, A is the cross-sectional area of the ground water flow, K is the hydraulic conductivity, and dh/dx is the hydraulic gradient in the direction of flow.

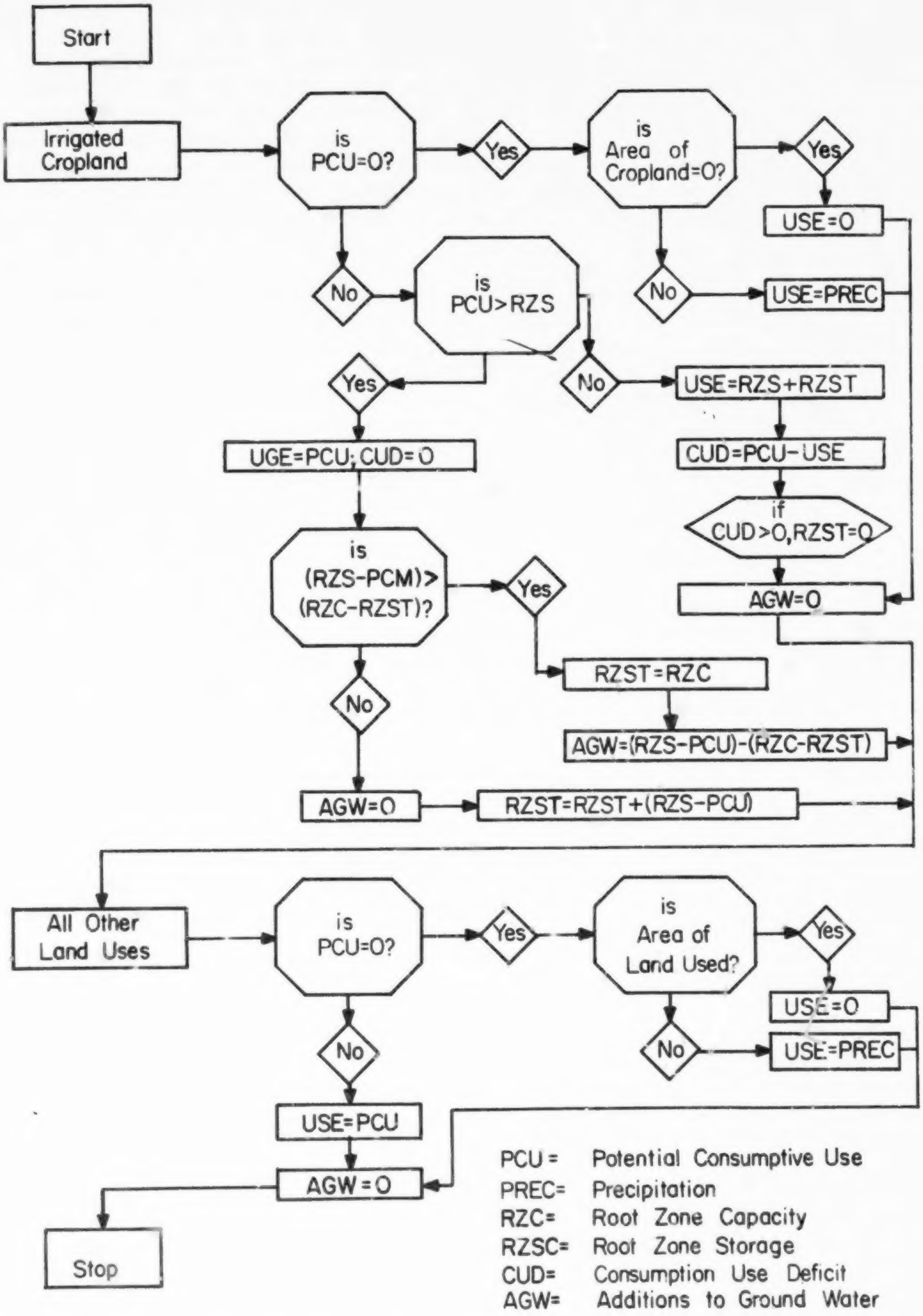

Start
Irrigated Cropland
is PCU=0?
Yes
is Area of Cropland=0?
Yes
USE=0
No
USE=PREC
No
is PCU>RZS
No
USE=RZS+RZST
Yes
UGE=PCU; CUD=0
CUD=PCU-USE
if CUD>0,RZST=0
is (RZS-PCM)> (RZC-RZST)?
Yes
AGW=0
RZST=RZC
No
AGW=(RZS-PCU)-(RZC-RZST)
AGW=0
RZST=RZST+(RZS-PCU)
All Other Land Uses
is PCU=0?
Yes
is Area of Land Used?
Yes
USE=0
No
No
USE=PREC
USE=PCU
AGW=0
Stop
PCU = Potential Consumptive Use
PREC= Precipitation
RZC= Root Zone Capacity
RZSC= Root Zone Storage
CUD= Consumption Use Deficit
AGW= Additions to Ground Water

Fig. 14. Illustrative flow chart of root zone budgeting procedure.

During the course of the investigation, it was felt that the weakest link in the data was in determining the values of hydraulic conductivity. However, it seemed reasonable to assume that the relative magnitude of conductivity between one strata and another could be determined with reasonable accuracy. With this type of data, it is possible to formulate two independent methods of calculating the ground water flows and thus to increase the accuracy of the hydrologic budgeting procedure by forcing an alignment between the two methods.

The ground water analysis illustrated in Fig. 15 involves the comparison of the ground water outflow based on a mass balance arrived at through a general budgeting procedure (inflow minus outflow equals storage changes), where computations of outflows are based upon measured hydraulic gradients and conductivity data. Because the model only uses relative magnitudes of strata hydraulic conductivity, the values are adjusted based upon their relative proportion until each value of monthly ground water outflow is consistent between analyses. Then, the variability of the computed values of hydraulic conductivity are examined. If they are homogenous, the model represents the "best fit" between all monitored data. The computation of ground water outflow based on Darcy's equation for a number of strata can be written:

$$Q = A_1 K'_1 \frac{dh_1}{dx_1} + A_2 K'_2 \frac{dh_2}{dx_2} + \cdots + A_n K_n \frac{dh_n}{dx_n} \quad .....(6)$$

where A_n is the area of the n^{th} strata, K'_n is the hydraulic conductivity of the n^{th} strata, and dh_n/dx_n is the hydraulic gradient acting on the n^{th} strata. Occasionally when no confining layers exist, the hydraulic gradients would be the same for each strata; however, in the Grand Valley an underlying cobble aquifer is partially confined. The discharge computed from Eq. 6 will generally not be comparable in magnitude to the expected values determined from the mass balance analysis for the following reasons:

(1) The measured values of conductivity can be in error and in different units. Usually conductivity is determined in in/hr while the ground water outflows will be in acre-feet/month. To avoid confusion, these inconsistencies are compensated for in the adjustments.

(2) It is often difficult to evaluate the respective strata areas accurately. Consequently, a representative thickness can be determined and then a convenient unit width selected for the computations. If this practice is used, the flows will be altered, but the adjustment can be absorbed in the adjustments to hydraulic conductivity.

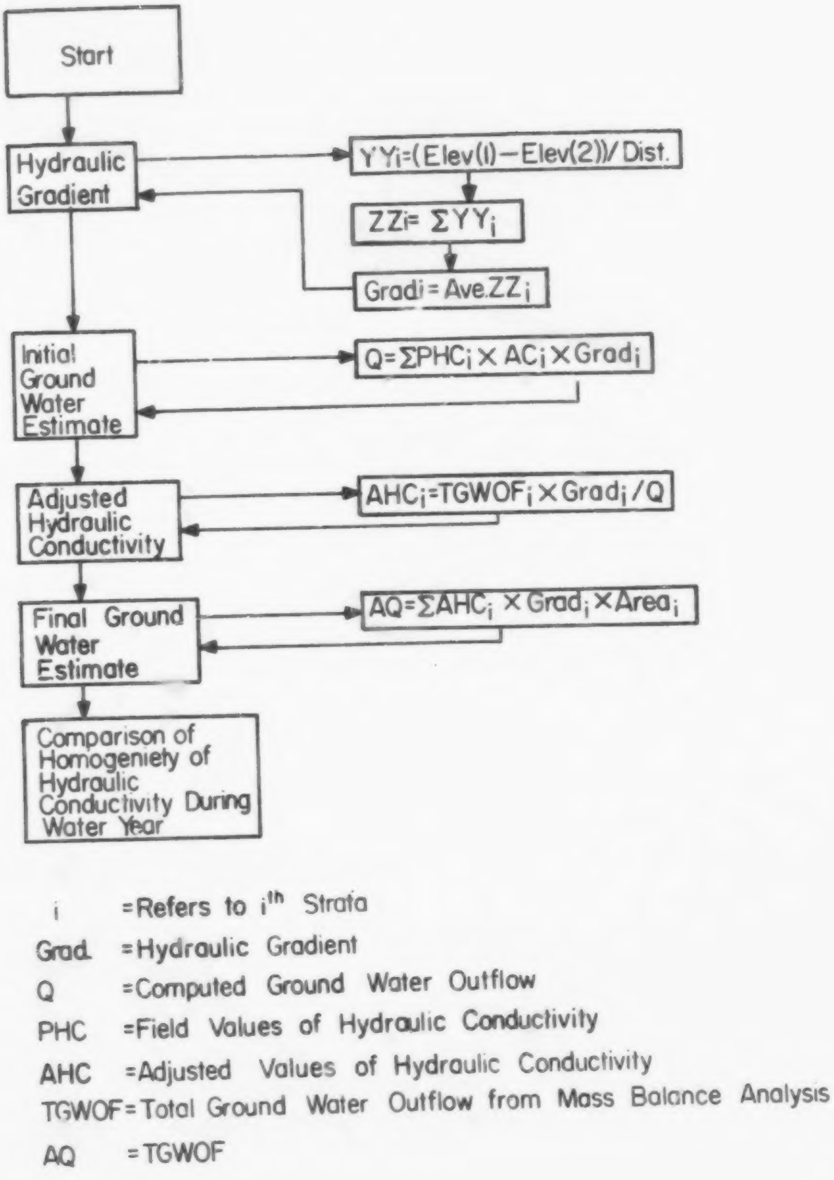

Start
Hydraulic Gradient
$YY_i=(Elev(1)-Elev(2))/Dist.$
$ZZ_i=\Sigma YY_i$
$Grad_i = Ave.ZZ_i$
Initial Ground Water Estimate
$Q=\Sigma PHC_i \times AC_i \times Grad_i$
Adjusted Hydraulic Conductivity
$AHC_i=TGWOF_i \times Grad_i/Q$
Final Ground Water Estimate
$AQ=\Sigma AHC_i \times Grad_i \times Area_i$
Comparison of Homogeniety of Hydraulic Conductivity During Water Year
i =Refers to i^th Strata
Grad. =Hydraulic Gradient
Q =Computed Ground Water Outflow
PHC =Field Values of Hydraulic Conductivity
AHC =Adjusted Values of Hydraulic Conductivity
TGWOF =Total Ground Water Outflow from Mass Balance Analysis
AQ =TGWOF

Fig. 15. Illustrative flow chart of ground water modeling procedure.

The adjustments to the field hydraulic conductivity measurements can be made as indicated:

$K_i = (TGWOF \cdot K_i')/(\text{value of discharge obtained from Eq. 6})$ ..(7)

where K_i is the adjusted hydraulic conductivity, TGWOF is the ground water outflow estimate from the mass balance analyses, and K_i' is the field measurement of hydraulic conductivity.

The salt flows in both the root zone and the ground water flow systems are important items that will be discussed in a later section.

In summary, the computational procedure for evaluating ground water flows, which is also used in this study as a basis for adjusting the complete hydrologic and salinity budgets, is as follows:

(1) From field data collected on hydraulic gradients and conductivities, along with physical dimensions of the system, a value of ground water discharge can be computed using Darcy's equation.

(2) Comparison of the values obtained in step (1) with the estimates of ground water outflows based on a mass balance analysis is used to adjust the field values of conductivity according to their relative magnitude until both methods of computing discharge agree.

(3) Compare the monthly values of adjusted hydraulic conductivity for homogeniety. If the values are found to be in error, all parameters in the hydro-salinity model are not aligned and further adjustment of various budget factors is necessary.

Outflows

The water leaving Grand Valley, aside from evapotranspiration, includes the river outflows and ground water flows occurring beneath the gaging station. Another common form of regional outflow is exportation, but in Grand Valley none of these exist.

River Outflows

The Colorado River exits from Grand Valley in the western end with a mean annual discharge of about 6,500 cfs and a salt load of about 900 parts per million of total dissolved solids.

The resulting salt pickup from Grand Valley during most normal water years varies between 0.7 and 1.0 million tons.

Ground Water Outflows

The estimated discharge under the exit gaging station operated by the U.S. Geological Survey has been shown to be small in comparison to the river flows (14). However, the reliability of this type of an assessment should be questioned in light of the difficulty of monitoring the subsurface outflow without undertaking a ground water study, which requires field drilling operations in order to provide the necessary data for computing the discharge below the ground surface.

Hydro-Salinity Model

The vast computational requirements requisite to formulating water and salt budgets, often called hydro-salinity modeling, is best facilitated by digital computers, or as in the case of Hyatt (14) by electric analog computing systems. The results of this study were derived from a digital program which has been reported previously (38). It may be helpful in other studies to discuss the general nature of the model program.

The mathematical model derived for this study attempted to simulate the hydrologic conditions of the agricultural system in Grand Valley, but the concepts are general and can be extended with modification to other areas that are similar in nature. The program was written in individual but interconnected subroutines that give the program a measure of flexibility during operations by separating the calculation phase from either input or output phases. Thus, several of the subroutines become optional if their functions can be replaced by input data, or if certain outputs are not desired. This general nature of the program is illustrated in the schematic flow chart shown in Fig. 16 with name and functions tabulated in Table 15.

The main portion of the program is used to read necessary input data and to control the order of water and salt budget calculations. There are certain advantages in separating the input, output and computational stages of a program including:

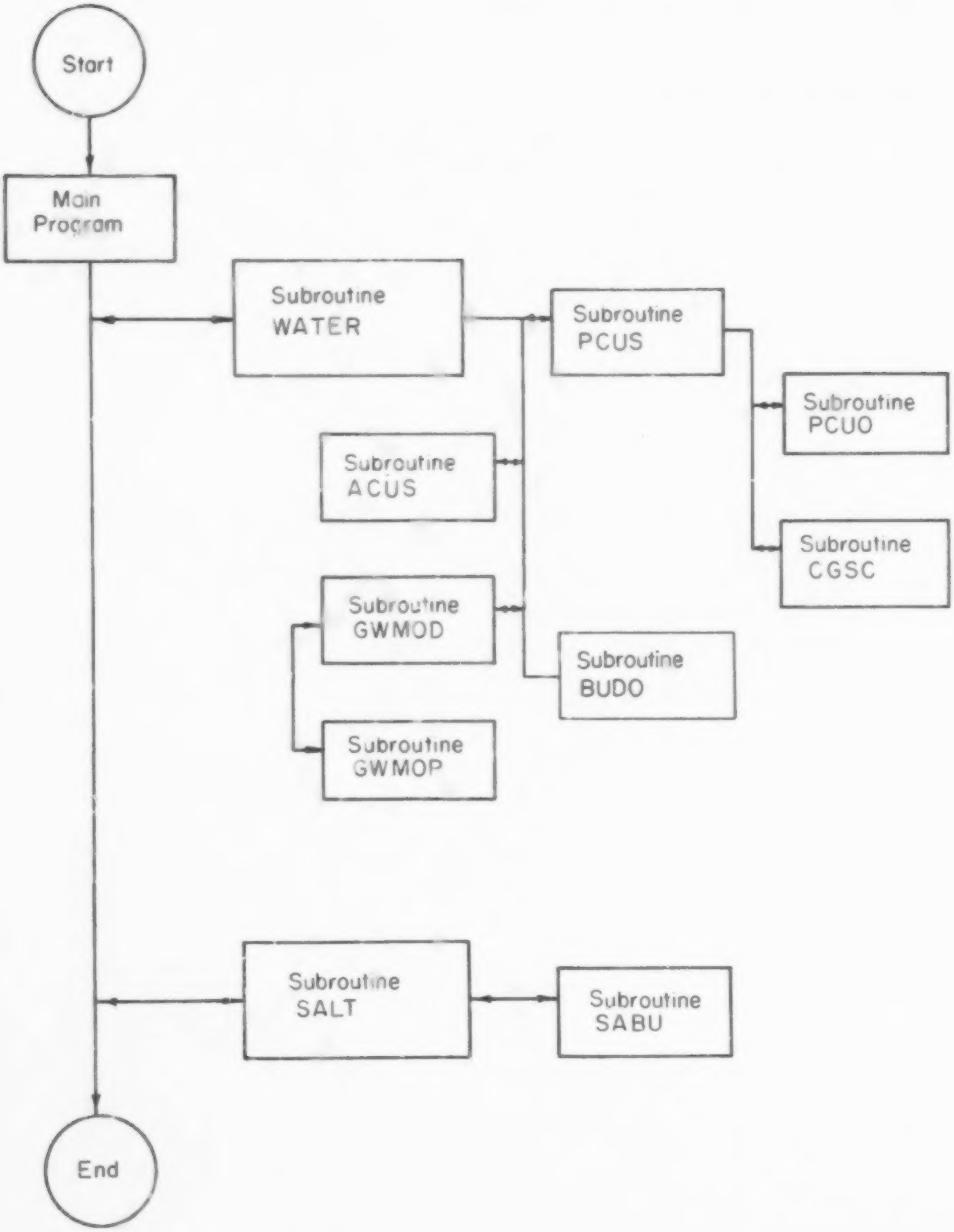

Start
Main Program
Subroutine WATER
Subroutine PCUS
Subroutine PCUO
Subroutine ACUS
Subroutine CGSC
Subroutine GWMOD
Subroutine BUDO
Subroutine GWMOP
Subroutine SALT
Subroutine SABU
End

Fig. 16. Schematic flow chart of hydro-salinity model.

Table 15. Hydro-salinity model subroutine descriptions.

Subroutine	Description
WATER	Computation of monthly and annual values of the water budget. Relatively little independent data is generated by WATER directly since it functions primarily as a summary.
BUDO	Outputs data generated from WATER as the water budget.
PCUS	Computation of monthly and annual value of potential consumptive use for irrigated crops, dryland crops, municipal uses, industrial uses, open water surfaces, and phreatophytes.
PCUO	Outputs data generated in subroutine PCUS.
CGSC	Outputs values of crop growth stage coefficients.
ACUS	Computation of the estimated actual consumptive use and the various root zone parameters.
GWMOD	Computation of the discharges through the ground water model and adjusted strata hydraulic conductivities. When these values of conductivity approach equality, the ground water outflows are correct.
GWMOP	Output of ground water model computations.
SALT	Computation of the salt budget for the area.
SABU	Output of salt budgets.

(1) Input order is not important as the data are completely available at all stages of computation.

(2) Variable sets of data can be utilized in the model when several budgets are desired, or when some form of integration is desired. This is especially useful when an area can be broken down into smaller dependent areas.

(3) The functions of the subroutines are independent of input, thereby making each subroutine a unit than can be implemented in other programs.

(4) Corrections and adjustments are easily made without detailed consideration to other segments of the program.

In controlling the computational order of the program, the main program separates the calculation of the water and salt budgets. Consequently, the modeling procedure involves only the water phase of the flow system. This has been possible in this study because of the detail in which data have been collected. Once the water flow system has been simulated, the individual flows are multiplied by measured salinity concentrations and converted to units of tons per month. At this point in the formation of the budgets, careful attention must be given to the salt flow system since irregularities may be present, thereby necessitating further model adjustments. Thus, when the final budgets have been generated, the salt system, ground water system, and surface flow system must be reasonably coordinated and additional reliability is assured.

SECTION VII

FIELD INVESTIGATIONS METHODOLOGY

The evaluation of canal and lateral linings as feasible salinity control measures depends to a large extent on the success of isolating and measuring the various segments comprising the water and salt flow systems discussed in the previous section. The primary emphasis of the study took place in Area I, the intensive study area shown in Fig. 6.

In the principal test area, the local effects of poor water management including canal and lateral seepage were significant. Hydrologic conditions could be studied in reasonable detail. An additional advantage of this location was that a majority of the irrigation companies in the valley would be involved in the demonstration, thereby facilitating the application of project results to other areas of the valley. The smaller test locations, Areas II and III, were selected to evaluate the effects of canal lining under different land conditions. These areas involved additional irrigation companies also.

In any investigation, a balance must be reached between the physical size of the area, level of funding for the project, and the detail with which the components of the system are to be studied. The detail of this investigation was sufficient to adequately meet the stated objective, as well as provide considerable insight into the Grand Valley salinity problem. The experimental design was comprised of two phases: (1) instrumentation, and (2) peripheral investigations.

The instrumentation in the study area indicated by Fig. 17 provided valuable data concerning many of the important water and salt movements. While some of the parameters were measured directly such as drainage discharges, lateral diversions, water quality, and precipitation, others were investigated indirectly. These budget parameters relate mostly to ground water movement and were monitored for changes using such techniques as piezometers, wells, and soil sample analyses.

Because so many of the water and salt subsystems cannot be evaluated directly by feasible methods, peripheral investigations are usually made in which a portion of the area is examined in detail for the reaction to changes in other parts of the flow phases. Such studies included farm efficiency studies, which indicate the relative proportion of

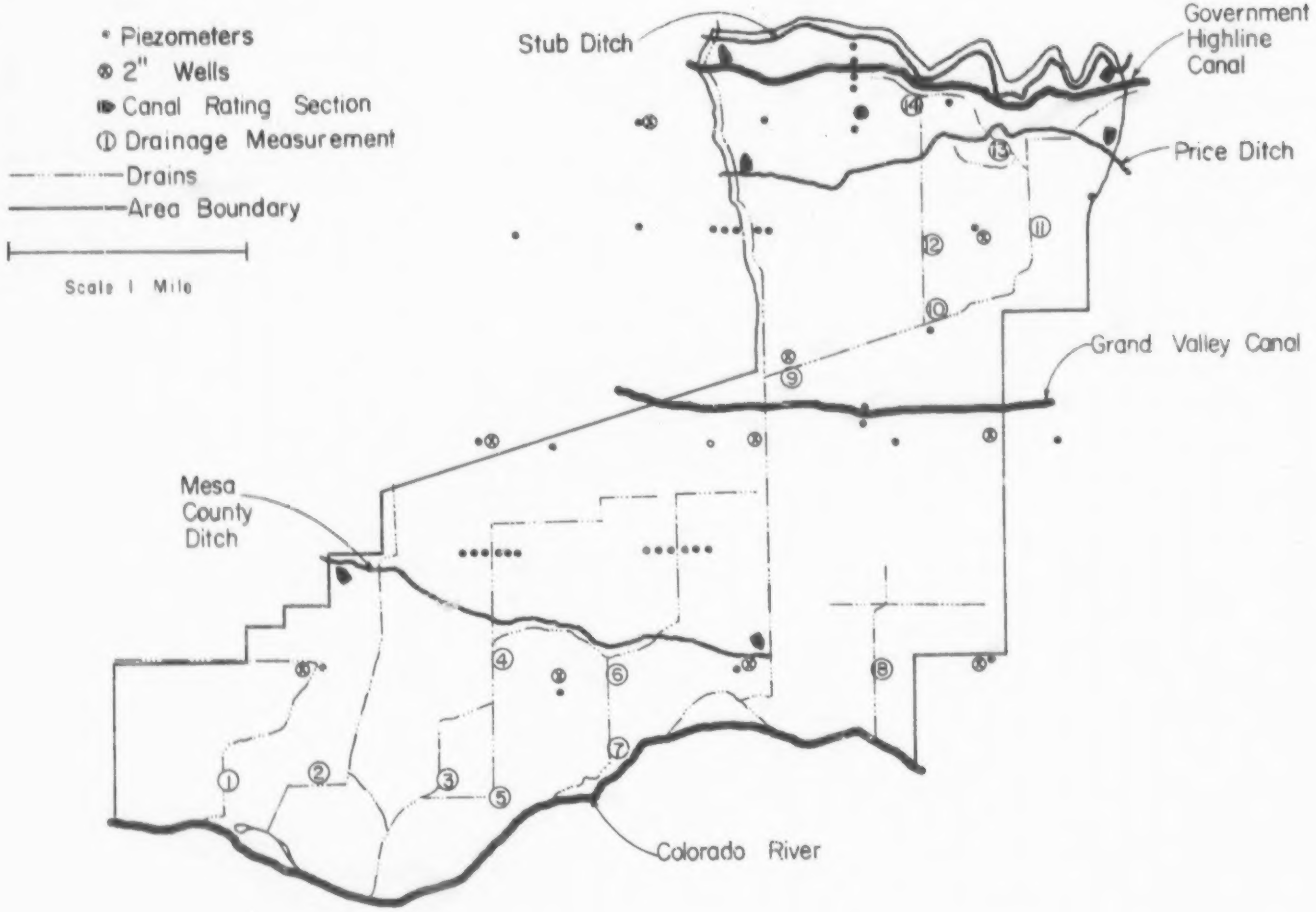

• Piezometers
⊗ 2" Wells
Canal Rating Section
① Drainage Measurement
Drains
Area Boundary
Scale 1 Mile
Stub Ditch
Government Highline Canal
Price Ditch
Grand Valley Canal
Mesa County Ditch
Colorado River
①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
⑪
⑫
⑬
⑭

Fig. 17. Location of instrumentation in Area I.

evapotranspiration, deep percolation, and soil moisture storage; land use inventories that yield the respective vegetative uses being made of the land area and the results of which are indicative of regional evapotranspiration; and others pertaining to specific areas of water and salt movement. Since these studies must be conducted on only a portion of the area under investigation, the assumption was made that they are representative of the rest of the area.

Instrumentation

The Area I instrumentation illustrated in Fig. 17 provided valuable data for analyzing the hydrology of the area. The data collected from these locations were used to delineate the canal and lateral diversions, drainage outflows, water table and aquifer pressure fluctuations, and water quality at the various locations. In order to gain a clearer picture of the type and limitations of data gathered from each type of measurement, it is useful to examine them individually.

Piezometers

The hydrostatic pressures and gradients in the region of alluvium between the cobble aquifer and the water table were studied using numerous clusters of 3/8 inch steel pipe piezometers. In each cluster, which contained three to seven piezometers, the depths were varied so the vertical hydraulic gradient could be evaluated. The small pipe sections were placed using a jetting technique shown in Fig. 18, and the same apparatus was also used to periodically flush the pipes to insure reliable readings. The procedure involved pumping water under moderate pressure through the pipe which loosened and carried away the soil below the end of the pipe, allowing the piezometer to be driven into the soil. Unfortunately, the method is quite inadequate when rocks or very heavy clay are encountered. For this reason, the piezometers extended only to the top of the cobble aquifer.

The piezometer installations have several essential uses in evaluating the subsurface conditions. These include:

(1) The fluctuations in the static pressure were used to evaluate both the vertical and horizontal hydraulic gradients in the area. The data from a cluster indicated the vertical gradients while the scattered clusters containing pipes of equal depth were used to establish the horizontal gradients.

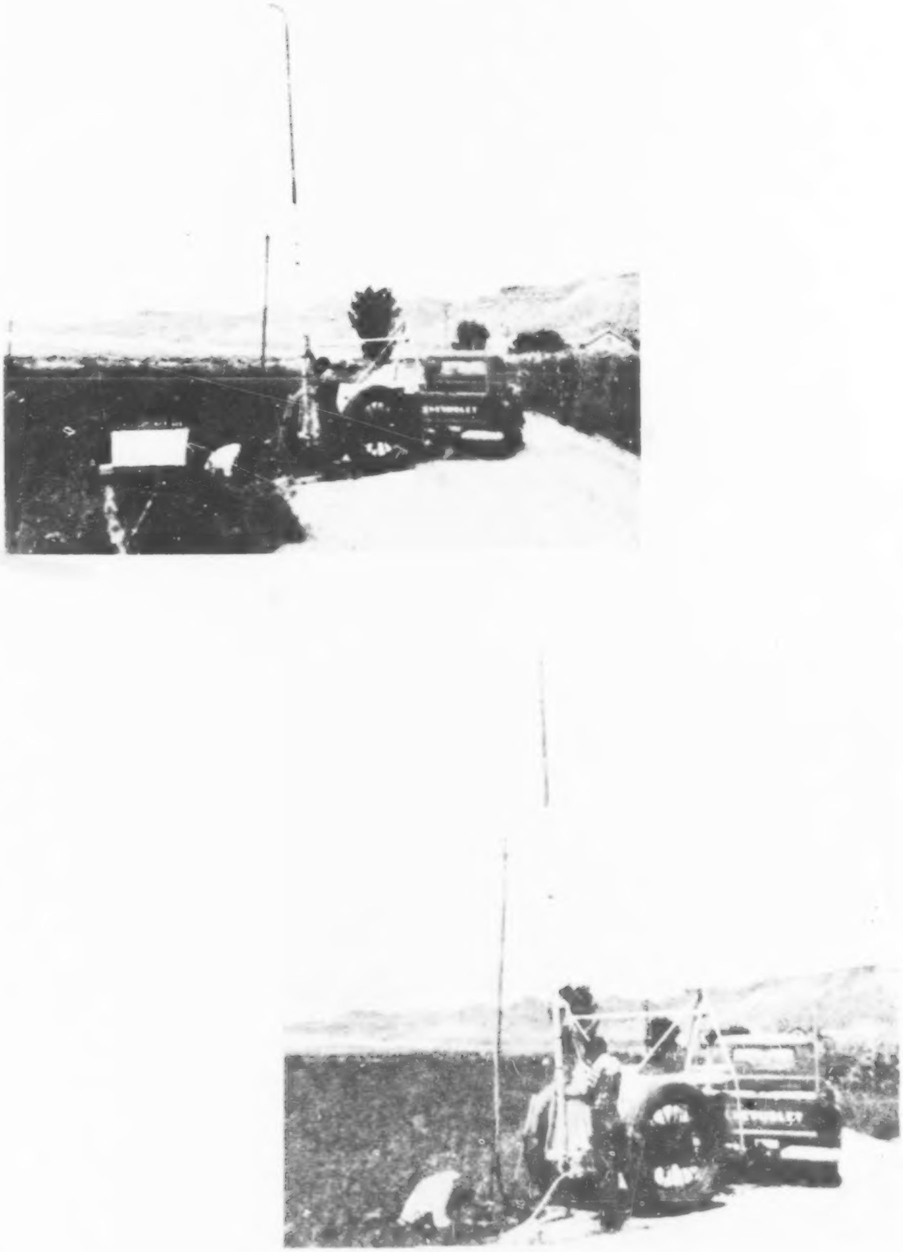


Fig. 18. Project personnel using the jetting technique to install pipe piezometers.

(2) Water quality samples were withdrawn from the pipes, yielding constituent breakdown, electrical conductivity, pH, temperature, and quantity of total dissolved solids. The analysis of these data was used to determine the seasonal changes in the quality of the ground water. Some generalization relating to drainage effectiveness and salt movements were also determined from these data.

(3) The piezometer locations were used to measure hydraulic conductivity of the soils employing the pipe-cavity method outlined by Kirkham (19). This information was then used in ground water discharge computations.

(4) Because of the high flows in the open drainage system, the possibility of certain sections contributing to the already acute overburden of the ground water system was studied by installing piezometer lines across selected drain sections. In this way, the water table level could be traced and thus establish whether or not the drain was performing as designed.

(5) Piezometer data throughout the area were examined to delineate areas of high or low water tables, vertical gradients, undulation in the topography of the cobble, and perched water tables. This information was also used in proposing alternate solutions to inefficient drainage.

Two-Inch Piezometers

Owing to the limitation of the piezometer depths, the examination of the movement of water and salt in the cobble aquifer was conducted by drilling two-inch diameter holes encased with steel pipe, with the bottom of the pipe being located on top of the Mancos Shale, in the middle of the cobble aquifer, or at the top of the cobble aquifer. The function of these instrument points has been essentially the same as that of the smaller piezometers. The larger diameter facilitates the collection of water samples and determination of water levels.

The drillers log from each installation defined the topography of the subsurface strata to and including the Mancos Shale. In addition, a few of the pipes were initially continued a small distance into the shale formation indicating the presence of small flows within the shale. Because the number and distribution of these larger piezometers is small, all pipes were installed in the overlying cobble strata and the influence of water inside the shale has been assumed small.

Flow Measuring Flumes

The small Parshall and Cutthroat flumes used in this study were not only used for monitoring drainage discharges as shown in Fig. 19, but were also used extensively as part of the special studies on farm efficiency, lateral seepage, and lateral diversions. At the most important locations in the area, flumes with continuous stage recorders were installed to minimize the error in evaluating these discharges. Since both of these type flumes are primarily designed for critical depth measurement, attention was given to insure that free flow (critical depth) conditions prevailed upon installation. Also, the flumes were continually monitored throughout the study to insure free flow conditions. By operating the flumes in this manner, only the upstream stage (flow depth) had to be recorded.

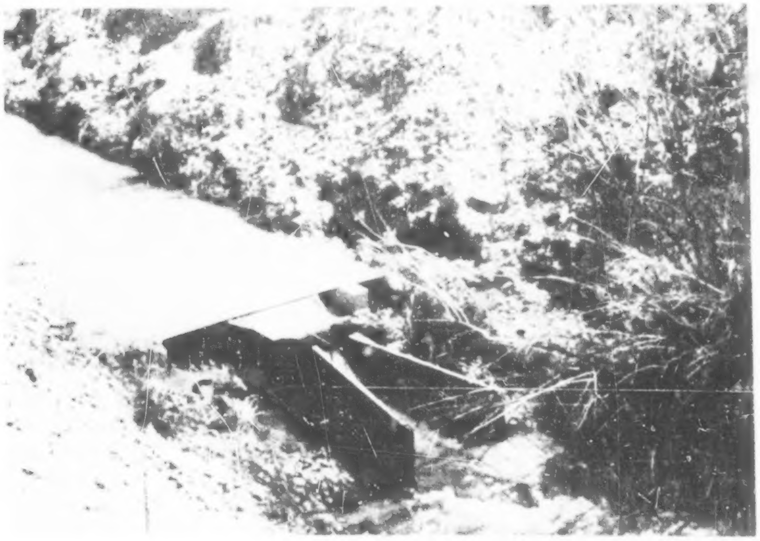
A typical installation was constructed by first placing sandbags in the channel to provide stability in the flume foundation, which was especially necessary in the open drains. Experience in doing this work showed other advantages were made possible, such as ease in leveling the flume, prevention of settling, and more effective sealing around the headwall of the flumes.

During the course of this study, the problem of maintaining free flow conditions in the drainage flumes was repeatedly encountered from channel moss, sediment, and high levels in the nearby river. In the cases where free flow conditions were impossible to maintain, the flumes were often raised; but occasionally this correction could not be made and considerable accuracy was lost. Fortunately, excellent efforts by the project personnel minimized these periods.

The flumes ranged in size from six-inch to one-foot Parshall flumes and one-foot to two-foot Cutthroat flumes. When properly installed and maintained, these flumes can be expected to measure a range of flows up to 13 cfs within about 5 percent accuracy. Those flumes equipped with stage recorders could also be examined for diurnal flow fluctuations, which provided some insight into the behavior of the system, but this type of analysis was made only occasionally during the study.

Canal and Lateral Section Ratings

An essential item in the analysis was the determination of quantities of water diverted from the canals into the lateral system for irrigation. This was accomplished in two ways:



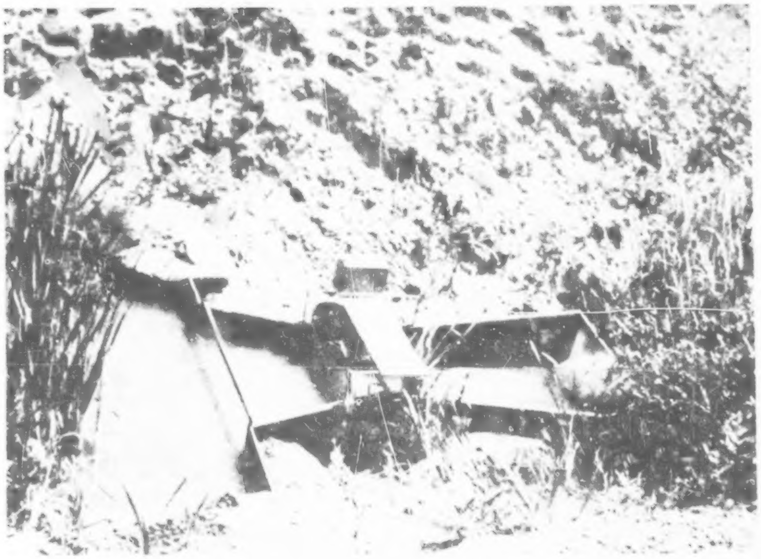


Fig. 19. One-foot Cutthroat flume located in an open drain in the test area.

(1) The smaller capacity canals such as the Stub Ditch, Price Ditch, and Mesa County Ditches were rated at both the inlet and exit cross-sections in the test area.

(2) The discharges in the Government Highline Canal and the Grand Valley Canal were so large (600-650 cfs) that the effor (e.g., the error would be 2-5 percent for a standard current meter rating) in the inlet and exit discharge measurements would be greater than the amount of diversions from the canal in the intensive study area. To remedy this situation, the turnouts from each canal were individually rated.

Prior to the beginning of the irrigation season, the relationship between height of thread rod and gate opening for each of the culvert type turnout gates, illustrated in Fig. 20, located along the lengths of the two large canals were determined. In addition, datum points were set which were used in referencing the flow depth upstream of the gate and the tailwater level at the culvert outlet. Then as irrigation was begun, daily measurements were taken on the gate opening, elevation of water upstream of the gate, and tailwater elevations. Since the individual rating of each gate required considerable time, much of the early data was collected but not analyzed until some time later. The rating procedure involved the placement of a Parshall flume downstream from the gate to measure the flow and then vary the gate opening over its possible range, noting while doing this the water level both upstream and downstream.

The rating for a submerged gate with the outlet submerged is given by:

$$Q = C_d A \sqrt{2g\Delta h} \quad \ldots\ldots\ldots\ldots\ldots (8)$$

where Q is the discharge in cfs, C_d is a discharge coefficient, A is the area of the moon-shaped opening characteristic of circular gates, g is the acceleration of gravity, and Δh is the difference in elevation between upstream (canal water level) and downstream (tailwater) water levels. In the situation where the downstream section is not submerged, the Δh term would be replaced by h_u, the upstream head above the invert of the culvert inlet. As the problem in the rating is to establish the value of C_d, the values of Q are plotted linearly against values of $A(2g\Delta h)^{\frac{1}{2}}$ or $A(2gh_u)^{\frac{1}{2}}$ and the slope of the resulting best fit line is C_d. It should be noted that a combination of hydraulic conditions can often cause the plot to be curvilinear. A typical rating curve is shown in Fig. 21.

The individual section ratings for the inlet and outlet cross-sections on the small supply canals were derived

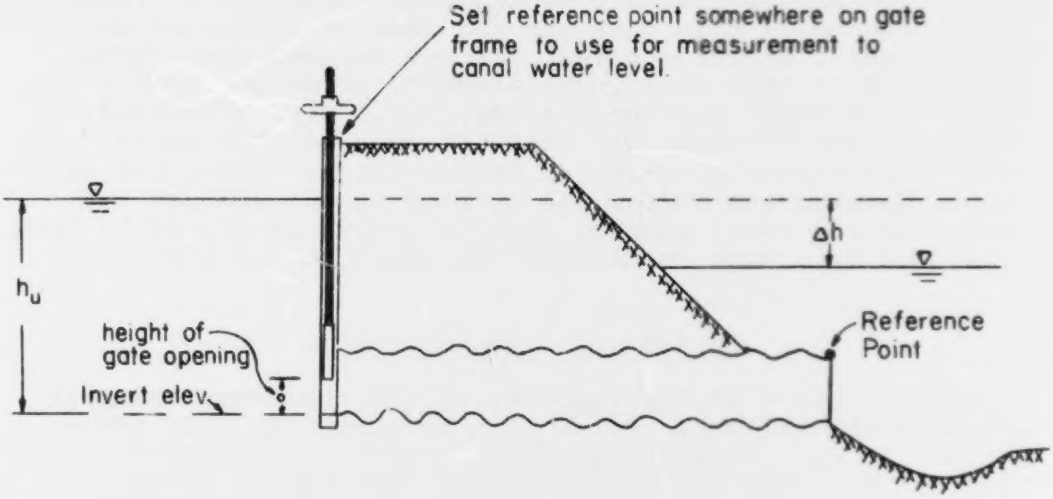

Set reference point somewhere on gate frame to use for measurement to canal water level.
h_u
height of gate opening
Invert elev.
Δh
Reference Point

Fig. 20. Typical lateral turnout structure used in the Grand Valley.

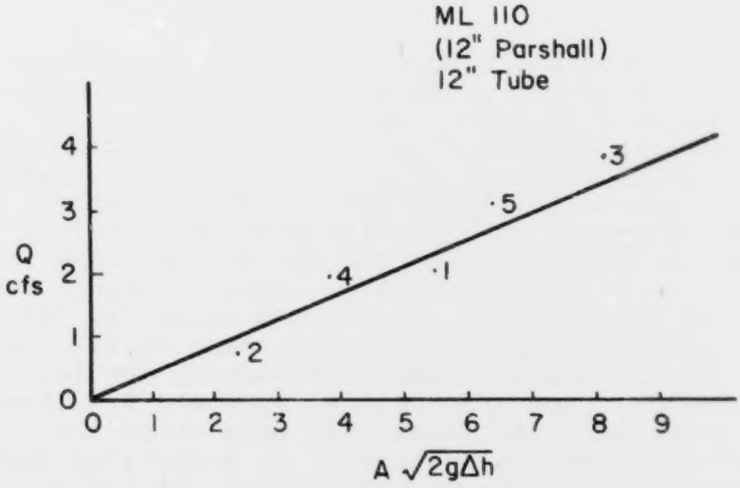


Fig. 21. Typical discharge relationship for a leteral turnout rated in the test area.

according to common U.S. Geological Survey stream gaging methods. Current meter measurements were correlated with daily readings of stage in these canals. One exception to this effort was the inlet to the Mesa County Ditch, which has a five-foot adjustable rectangular submerged orifice. The procedure in this case was the same as indicated above for the small circular gates. It was assumed that during the period of this study, the elements affecting such a rating like moss, bank vegetation, etc., were minimized. Once this relationship has been established, the daily stage readings were converted to discharge. Then, the difference between the inflow and outflow was determined and corrected for canal seepage loss to arrive at the daily farm diversion from that section of the canal in the test area.

Peripheral Investigations

Because a number of the segments within the water and salt system could not be measured with conventinnal instrumentation, it was necessary to conduct special studies of these items involving primarily the measurement of variables that are known to influence the parameters in the modeling process.

Land Use Inventory

The quantity of water transpired from vegetation surfaces or evaporated from soil and water surfaces can only be measured using expensive equipment. As an alternative, the computational methods discussed in an earlier section can be used conveniently, although some accuracy may be traded. In order to meet the data requirements of these methods, it is necessary to determine the type and area of each land use. This analysis was performed for the entire Grand Valley (39) with the data subdivided by sections within townships and also by section within townships served by individual canals. The procedure involved carrying aerial photos (1 inch = 1000 feet) into the field and marking the various land uses according to the index listed in Table 9. Then, the data were transferred to inked base maps where the acreage of each land use was evaluated. A summary of these results has been presented in an earlier section and will not be further analyzed. Also, a more complete report of the land use study has been published (39).

While conducting the land use surveys of the valley, the problem of poor drainage capacities of the soils was visibly apparent. Although these conditions have persisted for some time, the changes are usually made so slowly that the total acreage of each classification also varies slowly.

Seepage Investigations

The seepage from conveyance channels in the three project areas of the study were examined in two parts: (1) lateral seepage in Area I, and (2) canal seepage in Areas I and III. This type of study was conducted before and after the linings had been constructed along the lengths of the Stub Ditch, Price Ditch, Government Highline Canal, and Mesa County Ditch. In addition, before and after measurements were made along the Redlands First Lift Canal.

The ponding method for determining seepage loss rates was selected to assure accurate measurements, especially in the large canals, since the degree of error inherent in using inflow and outflow measurements procedures would tend to mask the magnitude of seepage losses. The ponding method, illustrated in Fig. 22, consists of placing an impervious barrier at two or more locations along the canal, filling each isolated section with water, and then taking periodic measurements on falling water elevations that can then be used to evaluate the seepage rate. The length of individual canals was diked into a number of ponds depending on the grade and length of the canal, with headgates extending through each dike in order to regulate water levels in subsequent ponds. The rate at which the water surface dropped in each pond was measured with either a staff or hook gage. Finally, a survey of the canal cross-sections provided the geometric data necessary for the rate computation expressed as:

$$Q_r = \frac{\Delta E \cdot SW_a \cdot 24}{WP_a \cdot T_r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

where Q_r is the loss rate in ft^3/ft^2/day (abbreviated as cfd), ΔE is the drop in water surface elevation in feet during the length of run, T_r is the time of the run in hours, SW_a is the average water surface width in feet tested during the run, WP_a is the average wetted perimeter in feet during the run, and 24 is the number of hours per day.

The lateral seepage study was conducted in a different manner because of the high grades and small flows. It should be noted again that the term "lateral" refers to the small conveyance channels that carry water between the canals and the fields. The Area I lateral system shown in Figs. 23, 24, and 25 was investigated using inflow-outflow discharge

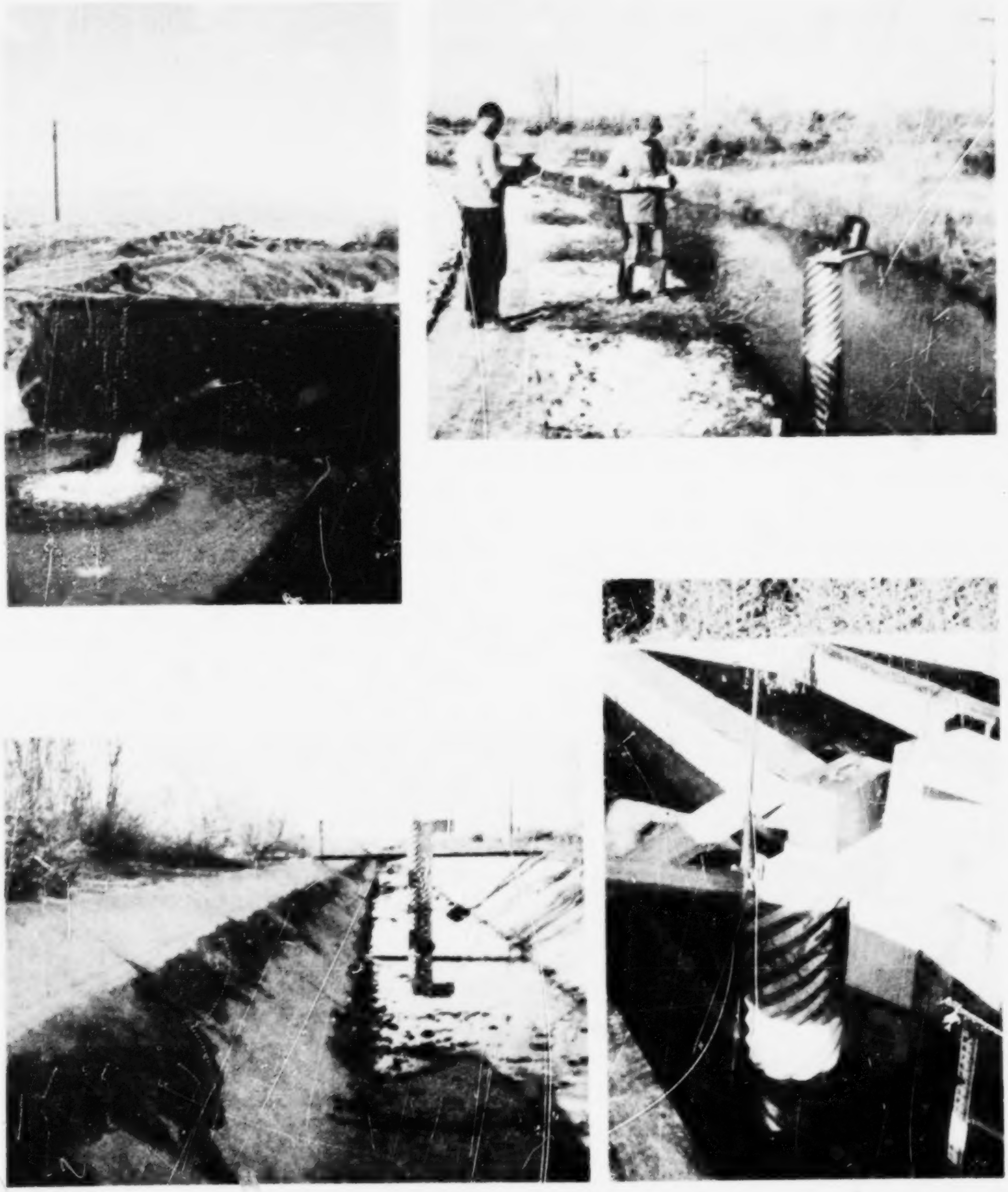


Fig. 22. Canal seepage measurement using the ponding method.

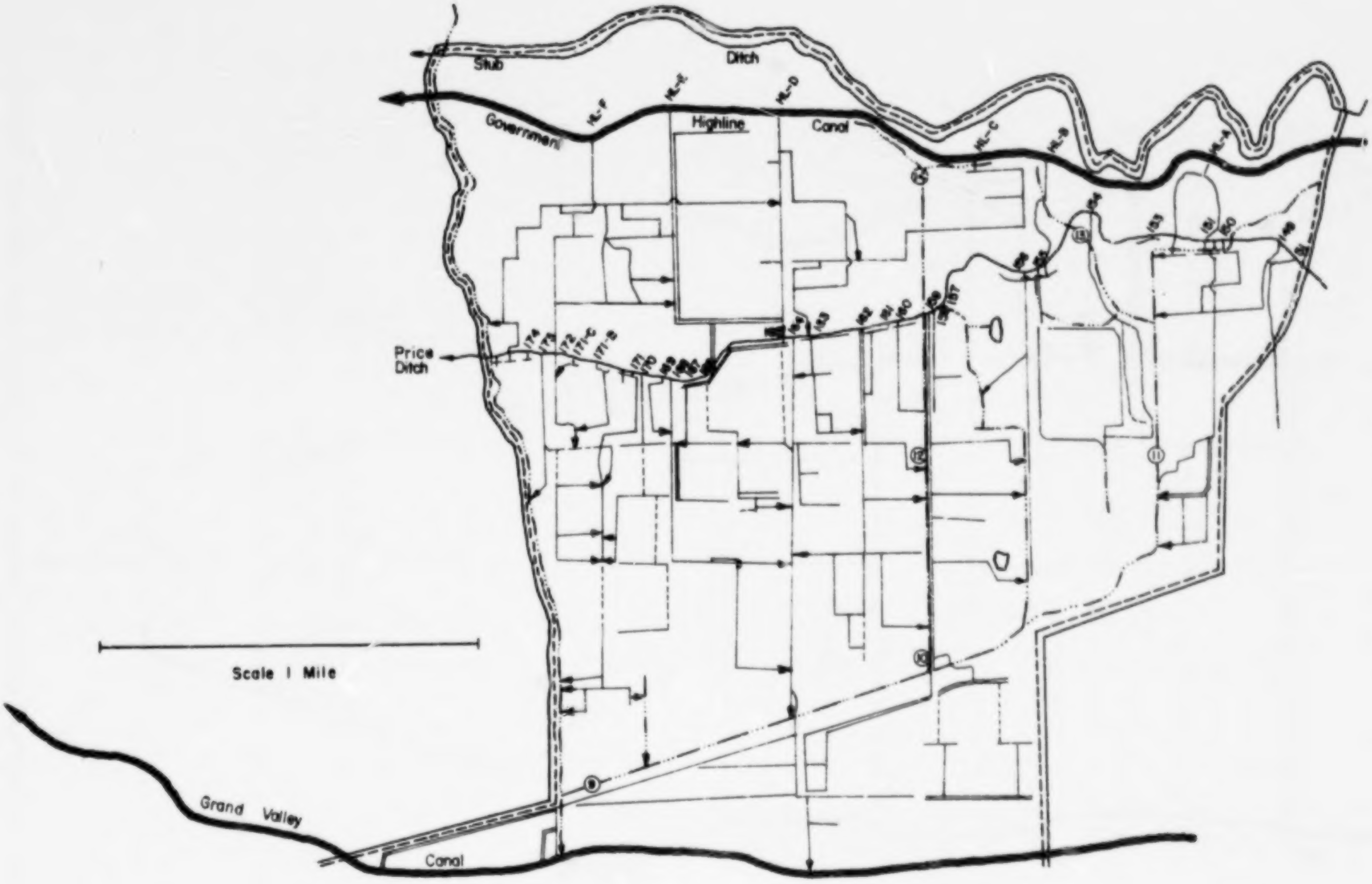

Stub
Ditch
Government
Highline
Canal
HL-F
HL-E
HL-D
HL-C
HL-B
HL-A
Price
Ditch
174
173
172
171-C
171-B
162
161
160
158
157
153
150
12
11
Scale 1 Mile
Grand Valley
Canal

Fig. 23. Lateral system supplied by the Stub Ditch, Price Ditch, and Government Highline Canal in Area I.

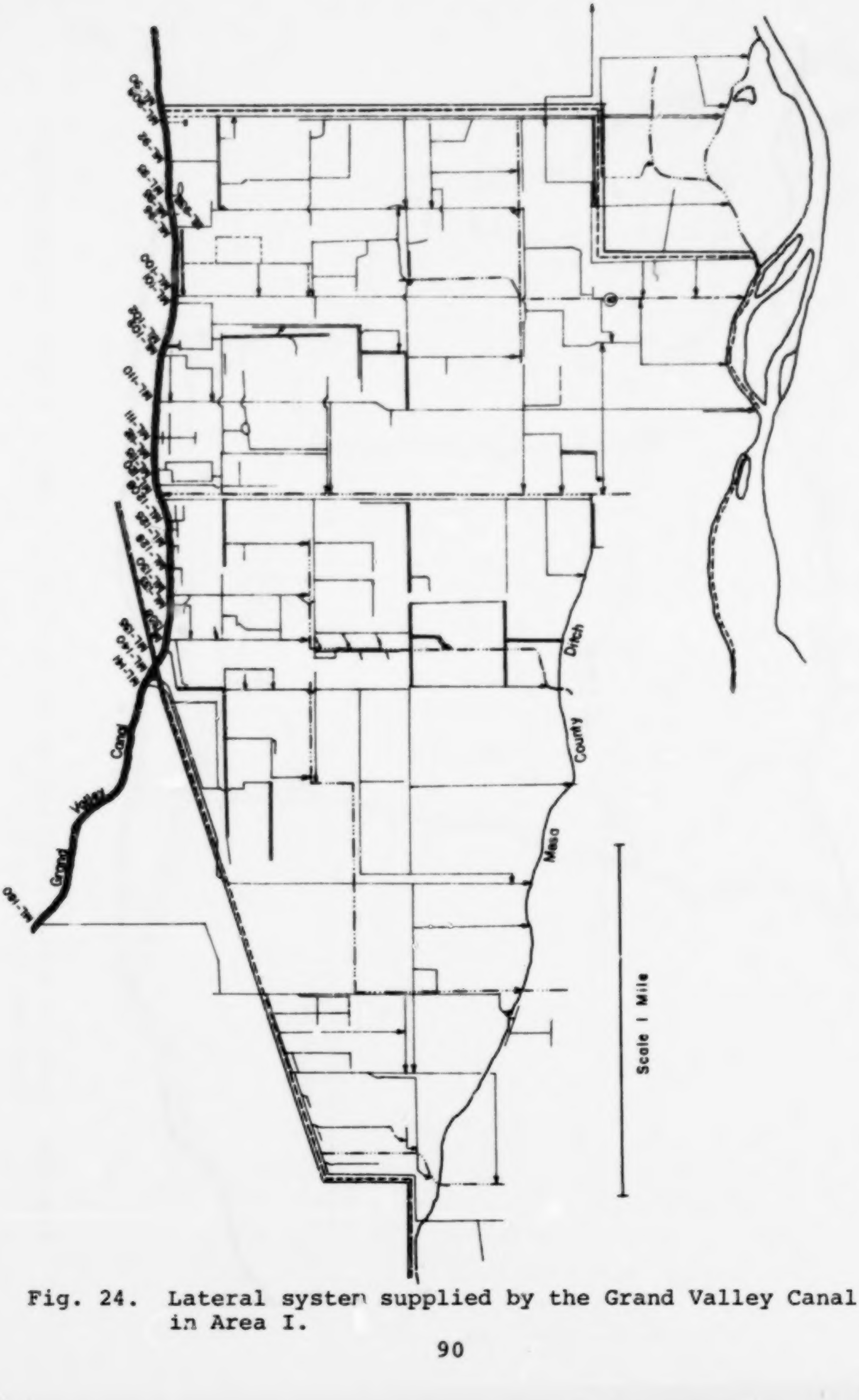

Grand Valley Canal
Mesa County Ditch
Scale 1 Mile

Fig. 24. Lateral system supplied by the Grand Valley Canal in Area I.

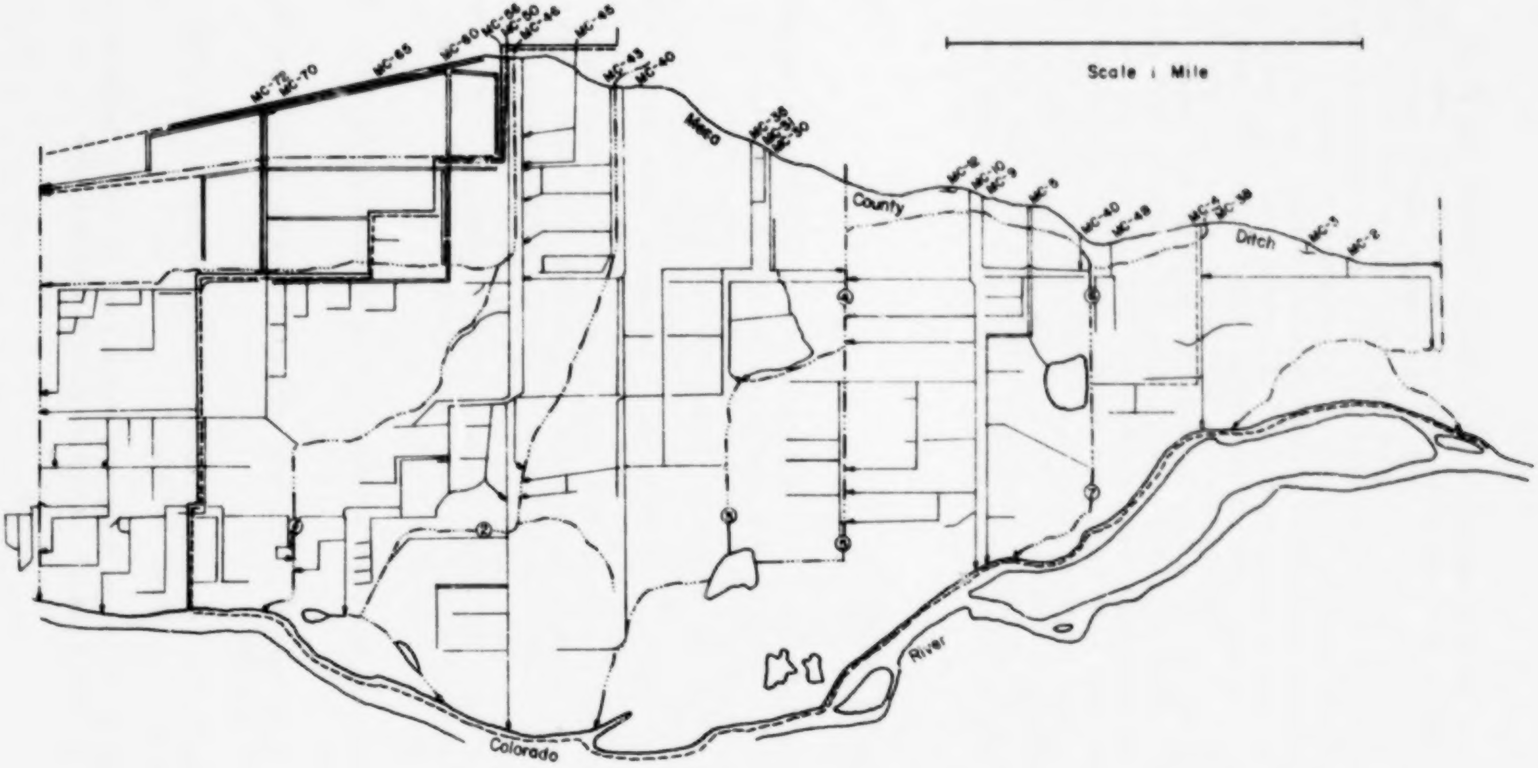

Scale 1 Mile
Mesa
County
Ditch
Colorado
River
MC-70
MC-65
MC-60
MC-50
MC-46
MC-45
MC-43
MC-40
MC-35
MC-30
MC-10
MC-9
MC-4
MC-3
MC-2

Fig. 25. Lateral system supplied by the Mesa County Ditch in Area I.

measurements. During most of the study, small Parshall flume flumes were used, but several unusual conditions were encountered where current meters and bucket-stop watch measurements were used. Flumes were located at the inlet and exit sections and at all inflows and diversions. The main channel sections usually required either a six- or nine-inch Parshall flume, while the inflows and diversions usually could be measured with two- and three-inch Parshall flumes. As the work progressed, two conclusions became apparent: (1) the seepage rate was small in comparison to the flows so a length of at least two thousand feet was necessary before the results would be relaible; and (2) the number of inflows and diversions must be somewhat restricted or the inaccuracy in the flumes, no matter how well operated, would be as large as the seepage loss in the section. Because of these limitations, not every lateral in Area I was suitable for measuring seepage loss rates. The procedure for an individual length of lateral could be satisfactorily completed during a day.

Farm Efficiency Studies

The efficient use of water on the farm would be achieved when the total quantity of water entering the field was sufficient enough to meet the demands of the crops, soil surface evaporation, and the quantity of water necessary to leach the residual salts of the evapotranspiration process from the root zone. Factors that decrease farm water use efficiency in Grand Valley are numerous and result in excessive deep percolation losses and high field tailwater flows. Irrigation efficiency is a good, although indirect, examination of the areal magnitudes of deep percolation, drainage interception, consumptive use, and field tailwater. As noted earlier, without expensive and complex instruments farm efficiency studies become the most feasible method of estimating these variables.

The principal parameters related to evaluating on-farm water use include:

(1) Field tailwater which was measured with small Parshall or Cutthroat flumes.

(2) Deep percolation and leaching requirements derived from budgeting the root zone flows.

(3) Root zone storage changes measured by soil moisture sampling and correlated neutron probe techniques.

(4) Evapotranspiration which was computed using methods that were discussed earlier.

(5) Uniformity of applications evaluated from soil moisture samples, as well as advance and recession analysis.

(6) Precipitation.

Since the initial phase of the project did not include soil moisture measurements, the results are primarily useful for analyzing irrigation methods and the extent of the surface flows. During the post-construction study phase, two farms (Fig. 26) were selected for study. In addition to the usual water budgeting analysis that was performed, advance-recession experiments were conducted in order to evaluate the effects of various irrigation practices on efficiency. Also, the analyses of soil samples for salt contents was added to this study so that the effect of irrigation on salt movement could be evaluated.

Subsurface Explorations

In addition to soil sampling efforts that gave considerable insight into the soil conditions, and piezometers and wells that indicated qualitative conditions below the root zone, an investigation was made throughout the test area to sample and evaluate salts and moisture content to a depth of about twenty feet. Examination of these data (summarized in Fig. 27) indicated the changes that are evident in the vertical section, and also showed the conditions throughout the region. One of the interesting generalizations that could be made from evaluating soil moisture and soil salt content throughout an area was the effects of poor drainage. For example, in the region in which the water tables were high, the process of capillary action and consequent evaporation from the soil surface would concentrate salts in the upper levels of the profile. The lower levels of soil profiles occurring in high water table areas were expected to have a more representative salt concentration of the area, since the water at these levels was slowly being drained. The exact opposite should be expected in well drained soils as the leaching action would remove salts in the root zone and concentrate them in the lower soil levels.

Drainage Evaluations

During the early stages of this project, the effectiveness of the open drainage system was questioned. As a result,

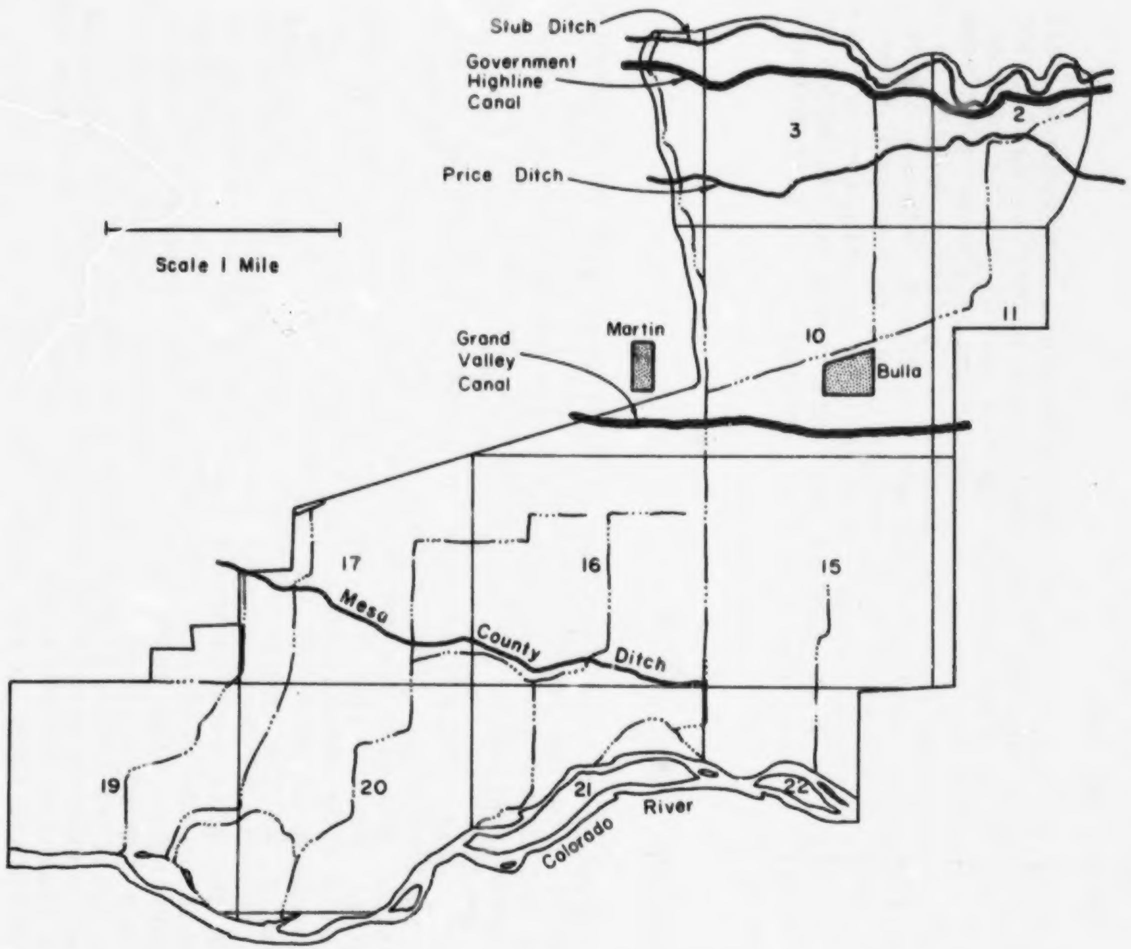

Stub Ditch
Government Highline Canal
Price Ditch
Scale 1 Mile
Grand Valley Canal
Martin
Bulla
Mesa County Ditch
Colorado River
2
3
10
11
15
16
17
19
20
21
22

Fig. 26. Location of farm efficiency studies conducted in Area I.

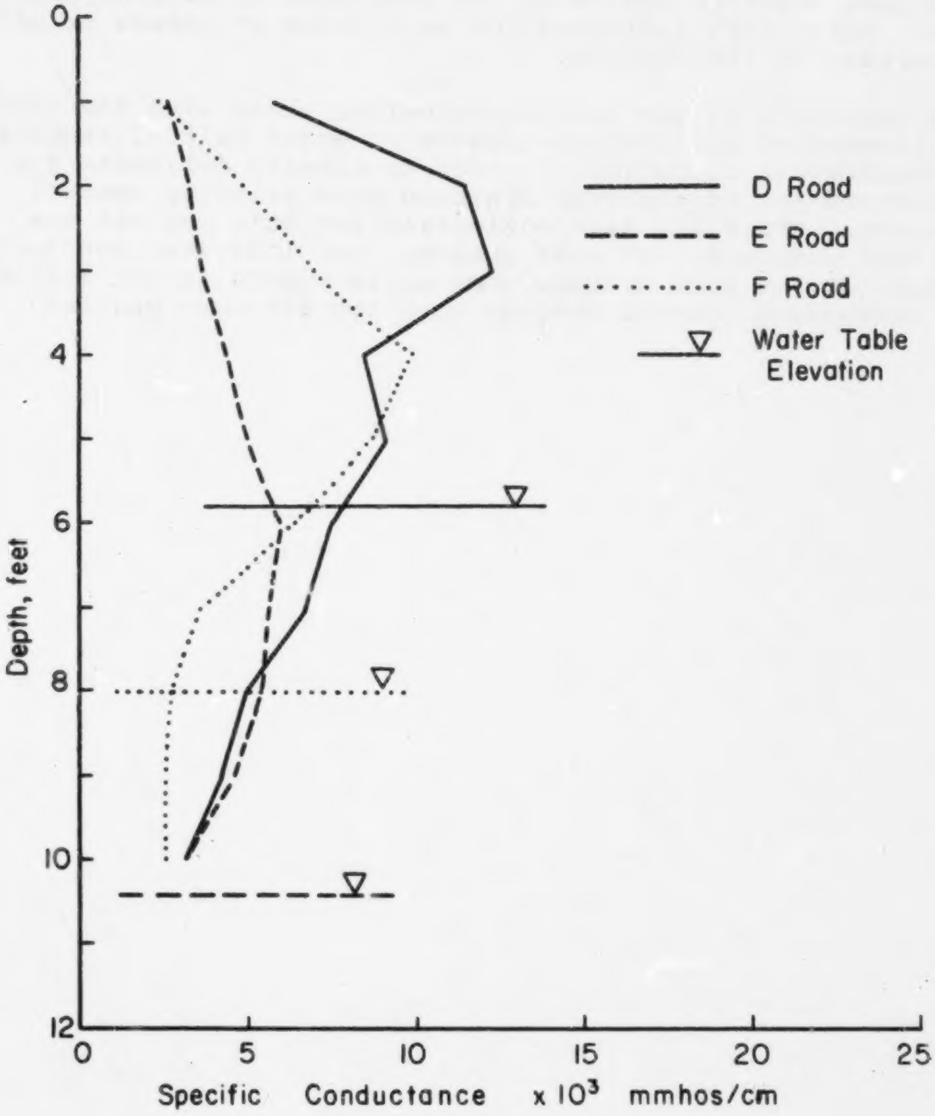


Fig. 27. Summary of Area I soil sampling data.

special piezometer installations were installed across certain drain sections to examine the piezometric surface as influenced by the drains. To complement the piezometer data, small Parshall and Cutthroat flumes were installed throughout the open drainage system in the test area to monitor discharges. These data indicated the magnitudes of losses or gains occurring in the reaches.

The magnitude of the salinity problem, along with the ineffectiveness of the drainage system in Grand Valley, required investigative attention in order to clearly delineate the effectiveness of improved drainage as a salinity control measure. While the data collection for this project was neither conducted for that purpose, nor indicated conclusive solutions, it does provide some basis regarding the influence of conveyance channel seepage upon the drainage problem.

SECTION VIII

WATER QUALITY CHARACTERISTICS OF THE GRAND VALLEY

With increasing water development in the Upper Colorado River Basin, effective salinity control measures are necessary to prevent extensive economic loss to lower basin users. Because the greatest impact of salinity is in the lower reaches of the river system (while most of the salt loads originate in the upper basin), the problem must be examined regionally. It is apparent that the alternatives available to the upper basin states relate almost exclusively to reducing salt inflows in order to offset transbasin diversions, as well as making reductions for the developments in the basin. Future increases in salt concentrations at Lee's Ferry, Arizona have to be minimized, or halted.

The feasibility of most of the presently conceived salinity control measures will be established in the near future. This project has examined, for purposes of reducing seepage losses, the possibility of lining conveyance channels. These seepage losses eventually transport large salt loads from the subsurface areas into the river system. However, most situations being encountered suggest that other management alternatives are not completely independent of canal and lateral lining or rehabilitation of distribution systems in general. For this reason, an attempt has been made in the following sections of the report to examine the results of this study in a broader perspective of salinity control measures, rather than just canal lining.

Neither the scope of this project nor the period of study justifies an extensive water quality data analysis. Nevertheless, a certain amount of discussion of the water quality characteristics of the area provides useful insight to the nature and problems of Grand Valley. Water quality data from the USGS stream monitoring stations in the Grand Valley area have been combined with a great deal of data collected as part of this study in order to reflect the chemical quality of the various segments of the hydrologic system in the valley.

The water quality parameters most representative of salinity include temperature, specific conductance, total dissolved solids, pH, calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulfate, and nitrate. This basic information can also be used to evaluate other indicator variables such as the relative activity of sodium. Water quality in an agricultural area varies with both discharge and the season. Thus, the water quality data have been grouped together according to the various hydrologic components of the water system and discussed in a general nature. The analysis of the Grand Valley water quality characteristics has been divided into the following groups:

(1) River inflows and outflows
(2) Drainage return flows
(3) Water table
(4) Aquifer flows

Surface Streamflow

The principal points of study relative to the valley inlet and exit sections are the U.S. Geological Survey stations from which all existing data were collected. These include:

(1) Colorado River, near Cameo, Colorado
(2) Plateau Creek, near Cameo, Colorado
(3) Gunnison River, near Grand Junction, Colorado
(4) Colorado River, at the Colorado-Utah State Line

Data relating complete constituent breakdown were extracted from USGS reports and summarized. In Fig. 28, the mean annual flow and its corresponding salt load in total dissolved solids expressed as tons are shown. The period of record was the 1969 water year. Several assumptions were made in arriving at this pictorial flow diagram. First, since no data were available, it was assumed that the water quality of Plateau Creek was the same as the Colorado River. Secondly, the estimates of precipitation and consumptive use were made from information reported by other researchers (7,14,16). Fig. 28 indicates that through Grand Valley there is a net consumptive use of 299,200 acre-feet and an input of one million tons of salt annually. About 55 percent of the consumptive use is from irrigated croplands. Taking into account all of the lands in Grand Valley, which includes lands with phreatophytes, the water use amounts to about 2.5 acre-feet per acre per year, while the salt contribution is 8 tons per acre annually. It should be strongly emphasized that these figures represent a period of one year and may not be representative of the general condition.

The information shown in Fig. 28 does indicate the magnitude of the flow system in Grand Valley, but further examination is needed to establish the specific effects. For example, Fig. 29 shows the mean annual flow diagram through the valley

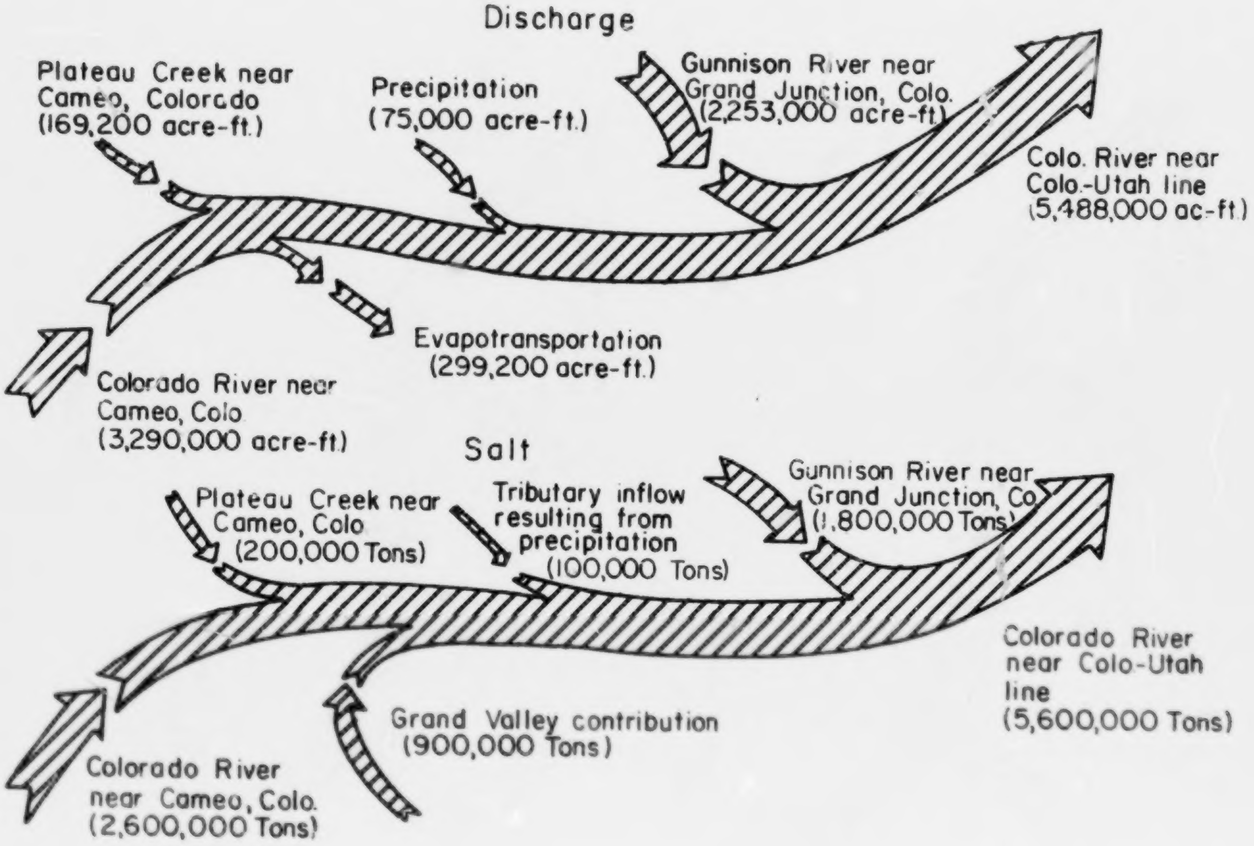

Discharge
Plateau Creek near Cameo, Colorado (169,200 acre-ft.)
Precipitation (75,000 acre-ft.)
Gunnison River near Grand Junction, Colo. (2,253,000 acre-ft.)
Colo. River near Colo.-Utah line (5,488,000 ac-ft.)
Evapotransportation (299,200 acre-ft.)
Colorado River near Cameo, Colo (3,290,000 acre-ft.)
Salt
Plateau Creek near Cameo, Colo (200,000 Tons)
Tributary inflow resulting from precipitation (100,000 Tons)
Gunnison River near Grand Junction, Co (1,800,000 Tons)
Colorado River near Colo-Utah line (5,600,000 Tons)
Grand Valley contribution (900,000 Tons)
Colorado River near Cameo, Colo. (2,600,000 Tons)

Fig. 28. Illustrative diagram of the water and salt flows in the Grand Valley area during the 1970 water year.

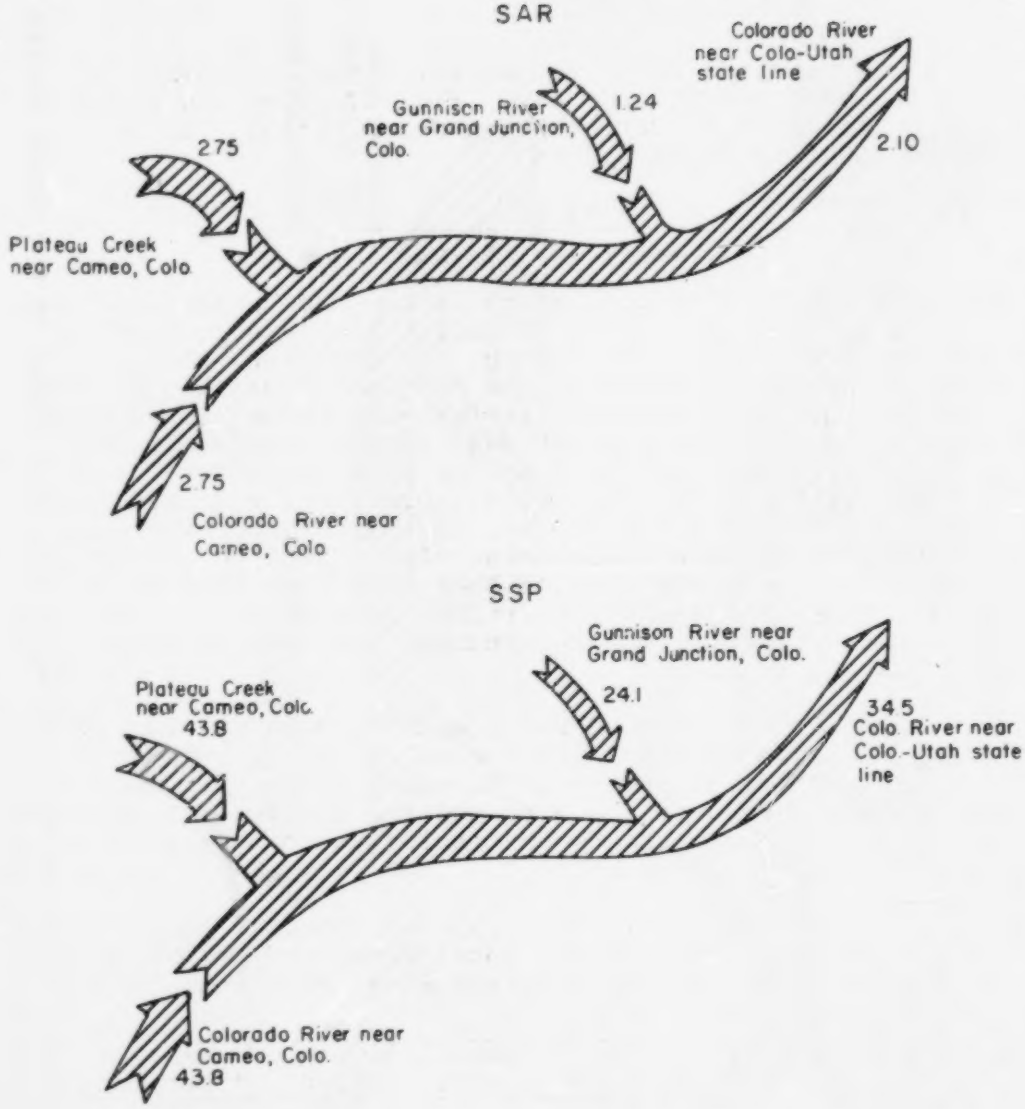

SAR
Colorado River near Colo-Utah state line
2.10
Gunnison River near Grand Junction, Colo.
1.24
2.75
Plateau Creek near Cameo, Colo.
2.75
Colorado River near Cameo, Colo.
SSP
Gunnison River near Grand Junction, Colo.
24.1
Plateau Creek near Cameo, Colo.
43.8
34.5
Colo. River near Colo.-Utah state line
Colorado River near Cameo, Colo.
43.8

Fig. 29. Diagram of sodium adsorption ratios (SAR) and soluble sodium percentage (SSP) in the Grand Valley during the 1970 water year.

in terms of the sodium adsorption ratio, SAR, expressed as

$$SAR = \frac{(Na^{+})}{\sqrt{\frac{(Ca^{++}) + (Mg^{++})}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

in which the brackets refer to the ionic concentration in milliequivalents per liter. Also, Fig. 29 shows the soluble sodium percentage, SSP, through Grand Valley. This parameter (SSP) is expressed as

$$SSP = \frac{(Na^{+})}{[(Na^{+}) + (K^{+}) + (Ca^{++}) + (Mg^{++})]} \quad \ldots\ldots\ldots\ldots (11)$$

Of specific interest to irrigators is the indication that the harmful dispersing attributes of sodium ions are reduced by the return flows from Grand Valley. In addition, the reduced SAR value at the mouth of the Gunnison River would also seem to indicate that upstream irrigation reduces the sodium effects, since the irrigated acreage in the Gunnison River Basin is much larger than that of the Colorado River Basin above Grand Valley. In order to delineate the magnitude of the ions in terms of annual flows, the cation breakdown has been summarized and presented (Fig. 30). Since no effort was made to evaluate the changes that occur in these variables with time, a frequency distribution diagram of SAR for the three principal gaging stations has been included in Fig. 31.

Further analysis of the USGS water quality data in the river system can be made by examining the relationship between total dissolved solids and specific conductance. Because of the limited nature of the data and the scatter encountered, the regression between the two variables was made linear. The results are tabulated below.

Table 16. Linear regression analysis of specific conductance in μmhos/cm and total dissolved solids in ppm for Colorado and Gunnison River stations. (EC = m·TDS + B).

Name of Station	Slope, m	Intercept, B	Correlation Coefficient, R	Number of Samples
Colo River near Cameo	1.247	177	0.970	29
Gunn River near G. Junction	1.132	119	0.998	43
Colo River at Colo-Utah State Line	1.372	176	0.970	12

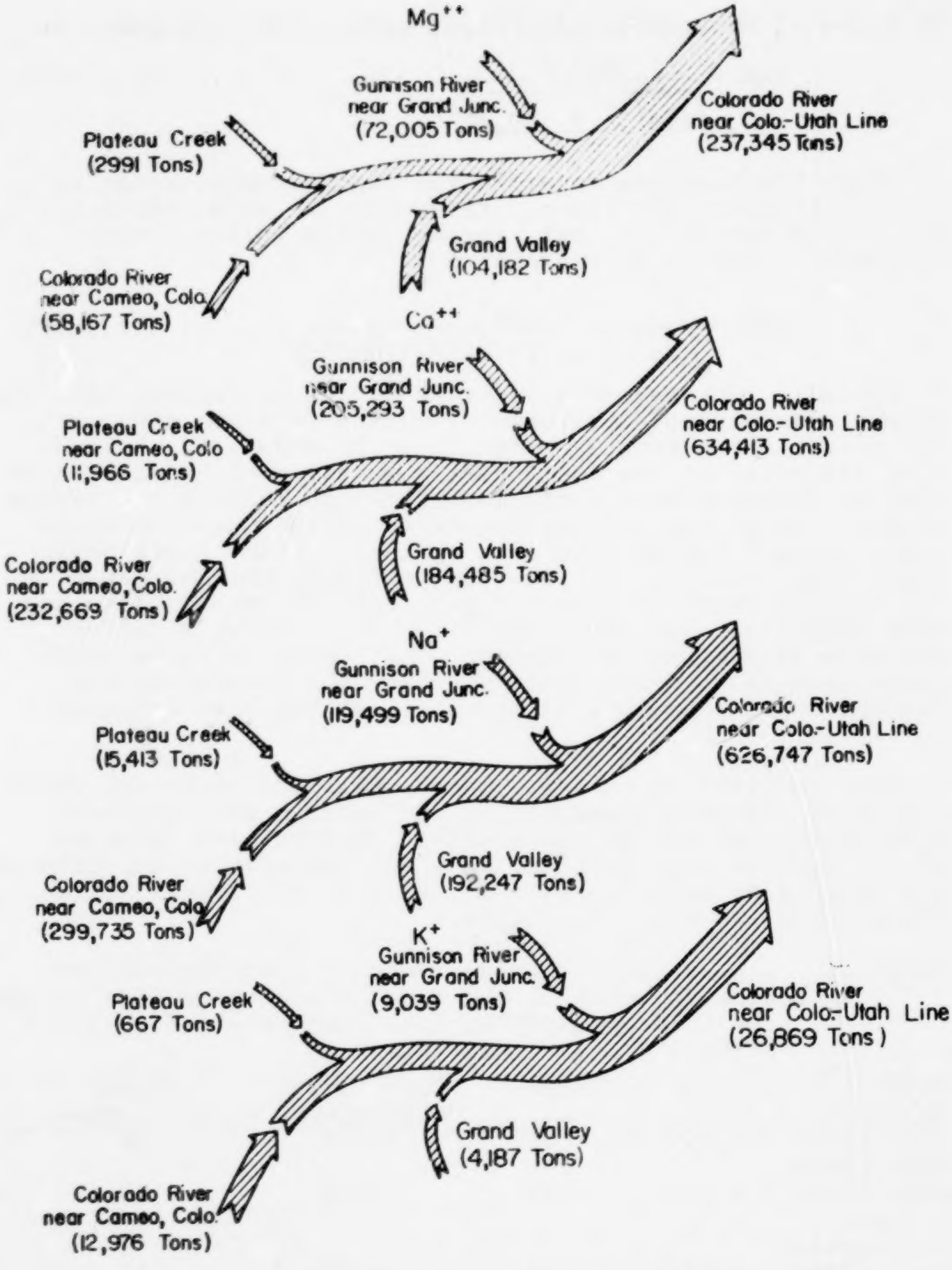

Mg⁺⁺
Gunnison River near Grand Junc. (72,005 Tons)
Plateau Creek (2991 Tons)
Colorado River near Colo.-Utah Line (237,345 Tons)
Grand Valley (104,182 Tons)
Colorado River near Cameo, Colo. (58,167 Tons)
Ca⁺⁺
Gunnison River near Grand Junc. (205,293 Tons)
Plateau Creek near Cameo, Colo (11,966 Tons)
Colorado River near Colo.-Utah Line (634,413 Tons)
Grand Valley (184,485 Tons)
Colorado River near Cameo, Colo. (232,669 Tons)
Na⁺
Gunnison River near Grand Junc. (119,499 Tons)
Plateau Creek (15,413 Tons)
Colorado River near Colo.-Utah Line (626,747 Tons)
Grand Valley (192,247 Tons)
Colorado River near Cameo, Colo (299,735 Tons)
K⁺
Gunnison River near Grand Junc. (9,039 Tons)
Plateau Creek (667 Tons)
Colorado River near Colo.-Utah Line (26,869 Tons)
Grand Valley (4,187 Tons)
Colorado River near Cameo, Colo. (12,976 Tons)

Fig. 30. Diagrammatic presentation of cation flows through the Grand Valley during the 1970 water year.

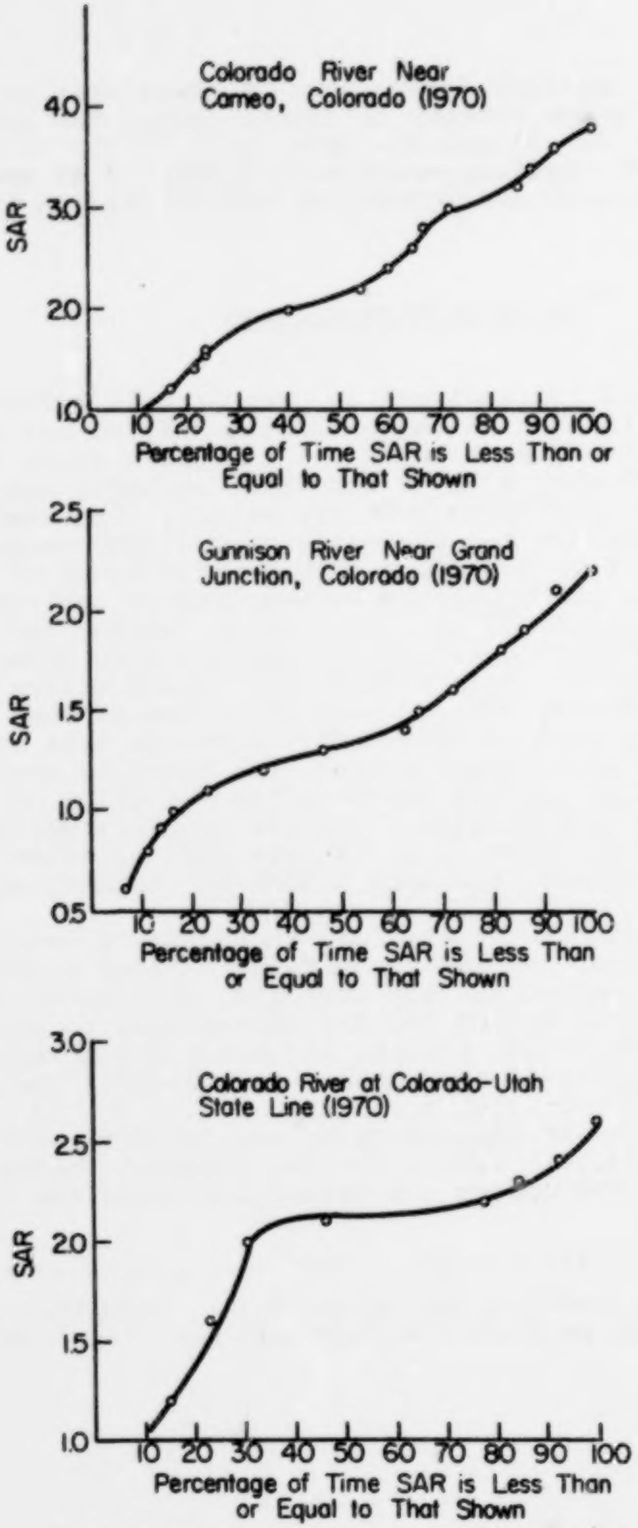


Fig. 31. SAR frequency at three USGS stream gaging station in the Grand Valley during 1970 water year.

The frequency of specific conductance at these stations, along with a bar graph summary of constituents, has been included in Figs. 32, 33 and 34. The ratio of TDS to EC for the Colorado River stations would vary between 0.62 and 0.70 for the usual salinity concentrations encountered in this river.

Drainage Return Flows

From data collected and analyzed as part of this effort, an analysis similar to that in the preceding section can be made. Samples from each drain in the intensive study area have been combined with a large number of periodic samples from drains and washes throughout the valley. The average constituent composition and frequency of specific conductance are shown in Fig. 35, along with the frequency of SAR. A point concerning the imbalance between anions and cations shown in the bar graph of Fig. 35 is made. During the analysis of the project data, all parameters were measured and recorded directly. As a result, some error exists in the laboratory analysis. Also, some constituents such as phosphate and iron were not measured, which can lead to an imbalance between cations and anions. In order to compare the average chemical quality shown in the bar graph of Fig. 35 with data specifically collected in the study area, Table 17 has been included to illustrate the variation in chemical quality between the open drains and natural washes.

Several considerations of these results should be noted. It has been assumed that the entire surface drainage system is similar, which is not completely correct. As pointed out earlier, many natural washes and drains are used to convey canal spillage back to the rivers, and every drain carries high percentages of field tailwater. Accordingly, there is a large dilution effect that occurs at various points within the system. The linear regression between specific conductance and total dissolved solids for the chemical quality data representative of the drains and washes indicates the following relationship:

$$EC = 333 + 0.851 \cdot TDS \quad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

with a correlation coefficient, R, of 0.981. When this particular regression was performed logarithmically, the R value was only 0.94.

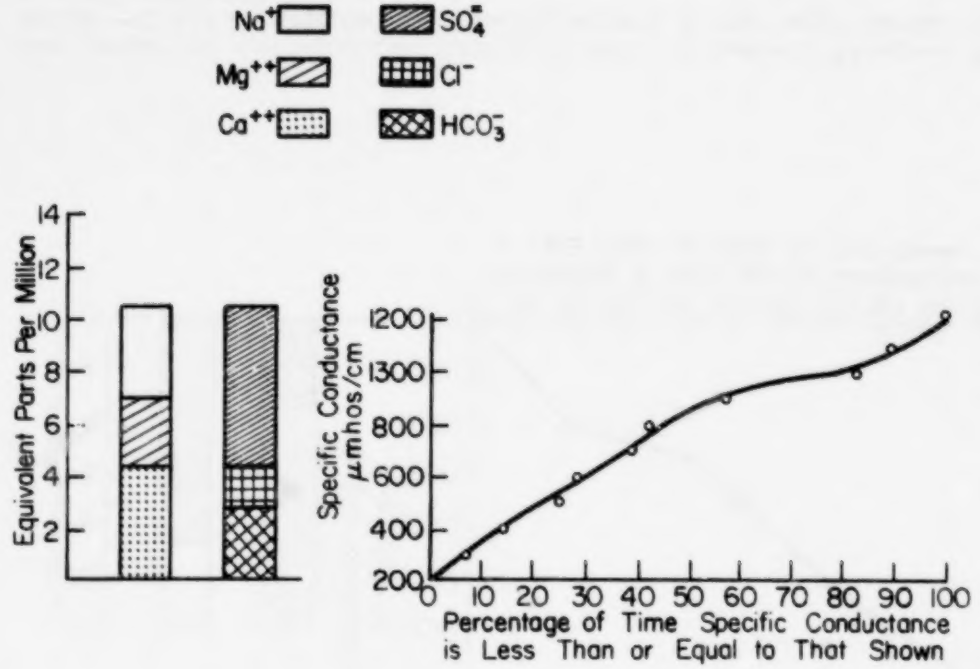


Fig. 32. Bar graph of constituent analysis and frequency diagram for specific conductance of water samples of the Colorado River near Cameo, Colorado during 1970 water year.

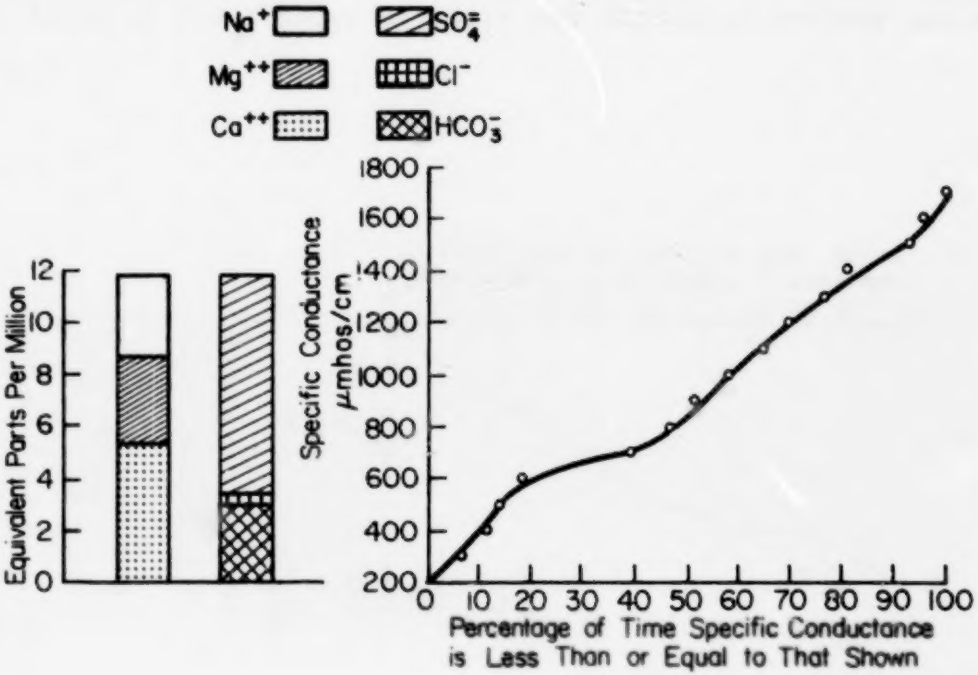


Fig. 33. Bar graph of constituent analysis and frequency diagram for specific conductance of water samples of the Gunnison River near Grand Junction, Colorado during the 1970 water year.

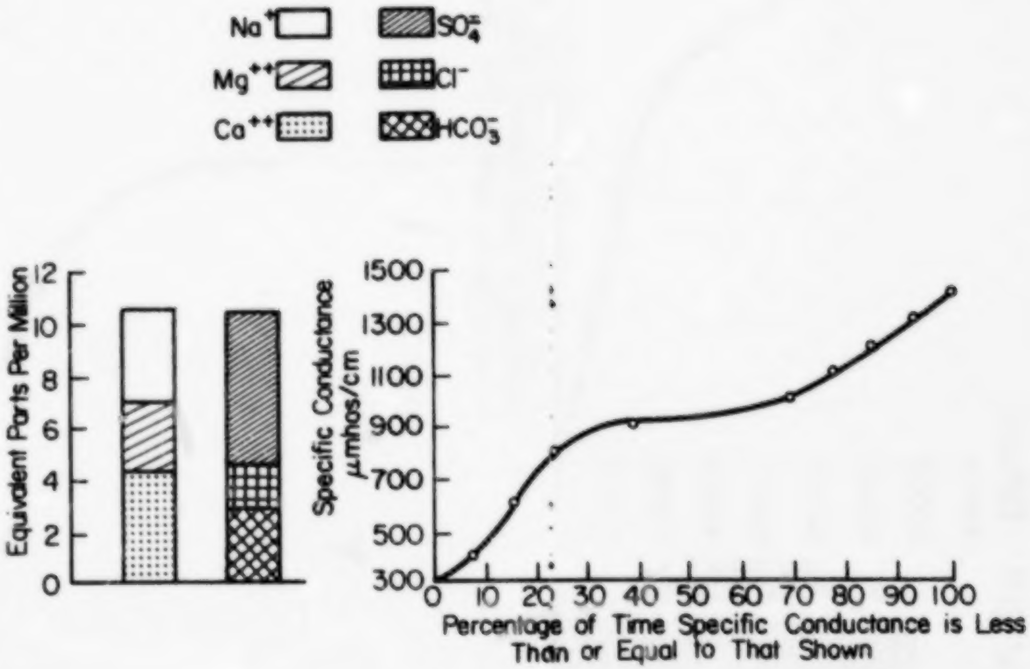


Fig. 34. Bar graph of salt constituents and frequency of specific conductance of samples from the Colorado River at Colorado-Utah State Line during 1970 water year.

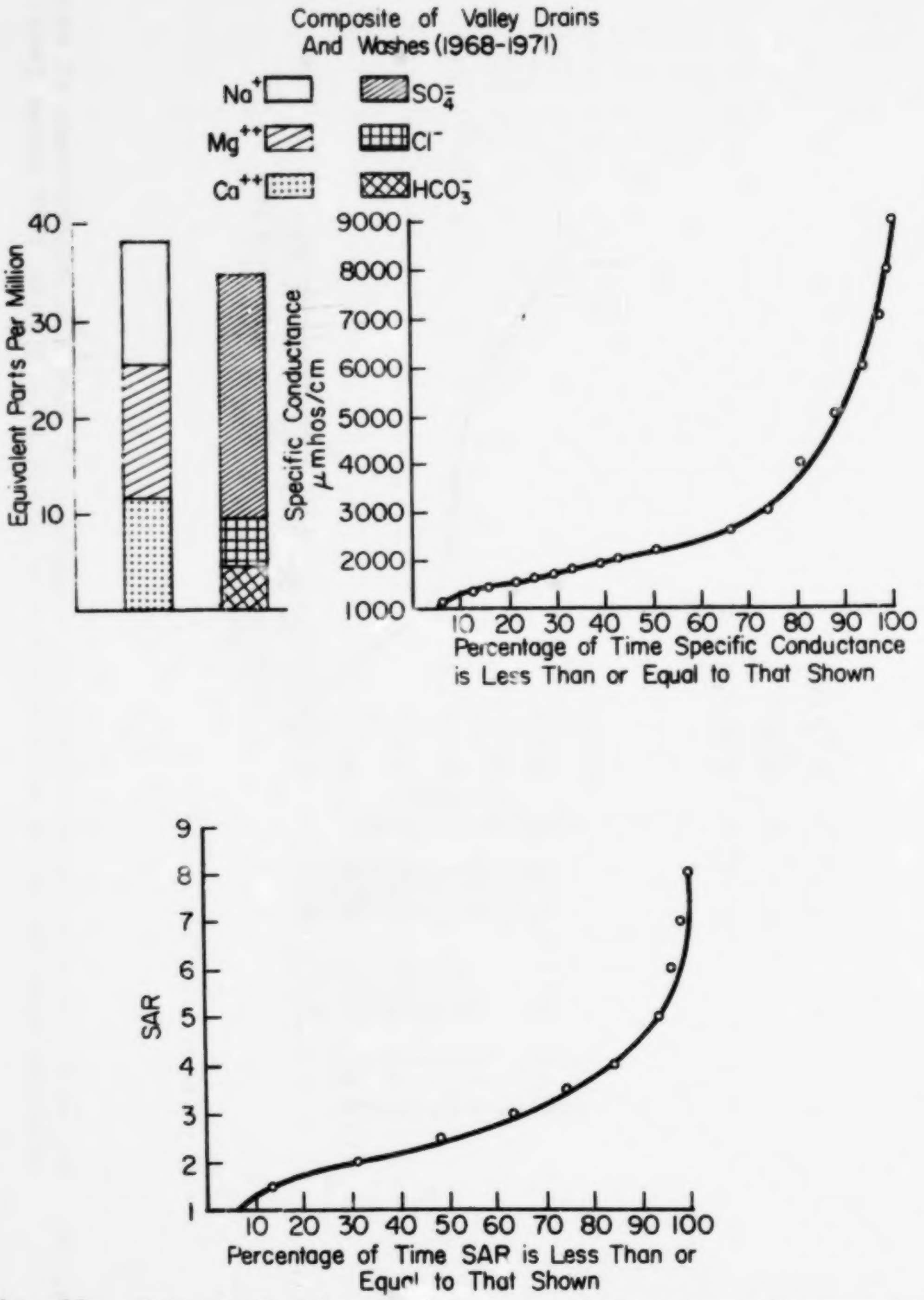


Fig. 35. Bar graph of constituents and frequency diagram of specific conductance of water samples for drains and washes in the Grand Valley.

Table 17. Average constituent breakdown in epm for drains and washes.

	Captions				Anions					SAR
	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^-	$CO_3^=$	Cl^-	$SO_4^=$	NO_3^-	
Flume 1	15.37	23.28	17.24	0.22	6.00	0.10	8.21	28.52	0.46	3.92
Flume 2	9.53	10.00	11.18	0.17	5.02	0.08	5.65	22.40	0.06	3.58
Flume 3	9.66	16.05	12.86	0.23	5.12	0.04	5.53	28.35	0.13	3.59
Flume 4	14.49	30.95	21.40	0.29	6.91	0.12	7.42	40.27	0.33	4.49
Flume 5	9.20	15.47	13.50	0.20	5.12	0.12	5.25	21.15	0.16	3.84
Flume 6	14.64	26.28	19.89	0.30	6.47	0.14	6.89	47.45	0.70	4.40
Flume 7	12.72	26.81	19.96	0.25	5.64	0.17	6.20	41.58	0.43	4.49
Flume 8	9.85	14.74	14.14	0.22	4.63	0.24	4.80	29.51	0.71	4.03
Flume 9	12.32	10.37	9.97	0.21	3.42	0.25	4.68	25.72	0.05	2.96
Little Salt Wash at HWY 6 & 50	5.86	8.98	10.29	0.14	3.64	0.13	3.42	12.49	0.15	3.78
Indian Wash at C-5 Rd.	12.68	18.33	16.29	0.35	4.31	0.13	5.49	32.09	0.79	4.14
West Salt Wash at HWY 6 & 50	10.70	11.31	12.77	0.17	3.77	0.12	3.48	17.07	0.11	3.85
Hunter Wash at River Road	10.70	8.77	12.27	0.20	3.81	0.05	3.73	20.32	0.19	3.93
Big Salt Wash at HWY 6 & 50	11.33	6.53	9.93	0.17	4.68	0.13	3.34	17.34	0.15	3.32
Mack Wash 1 mi west of Mack, Colo	12.07	9.69	6.93	0.15	3.08	0.16	2.82	10.49	0.13	2.10
Badger Wash at HWY 6 & 50	13.10	12.66	12.28	0.19	4.30	0.19	3.14	22.62	0.24	3.42
East Salt Wash at HWY 6 & 50	13.46	12.34	12.24	0.22	4.35	0.18	4.51	19.95	0.21	3.41
Composite Average of Drains & Washes	11.56	13.93	12.61	0.21	4.50	0.15	4.88	25.00	0.28	3.53

Near-Surface Ground Water

The collection of samples from piezometers located in the intensive study area was difficult at best. Often the sample was too small for analysis, and at other times no sample could be obtained. For this reason, a large number of samples of water below the water table were made, but the number for each individual peizometer was small. The frequency of SAR along with the constituent analysis and frequency of specific conductance are illustrated in Figs. 36 and 37 respectively. An attempt was made to evaluate the relationship between EC and TDS with the result

$$EC = 0.913 \cdot TDS + 100.0 \quad \dots\dots\dots\dots \quad (13)$$

in which R = 0.97. Although the coefficient of 0.913 is very high in comparison with the usually quoted ratio of 0.64 (TDS/EC), this result is corroborated by water quality analyses performed by the USBR on samples collected from drains and washes in Grand Valley.

Deep Ground Water

The water quality data collected from the two-inch wells in the cobble aquifer are summarized by frequency of SAR and EC, along with a bar graph indicating chemical composition in Figs. 38 and 39 respectively. The regression analysis indicated the following relationship:

$$EC = 1.00 \cdot TDS + 0.5 \quad \dots\dots\dots\dots \quad (14)$$

with a correlation coefficient, R, of 0.94. Again, the ratio of TDS to EC is very high, being 1.00. The EC and TDS values consistently have nearly the same value for the drainage waters, where salinity concentrations of 5,000 - 10,000 ppm are encountered, with occasional samples having EC and TDS values of 15,000 (mg/l or micromhos/cm).

Summary and Conclusions

Although a severe degradation in water quality (as measured by increased TDS levels) occurs in Grand Valley, an examination of several indicator parameters, such as the sodium adsorption ratio, show that the activity of sodium is being reduced. Since much of the salt contribution from the Mancos Shale is primarily Ca, Mg, and SO_4, a reduction in SAR would be expected.

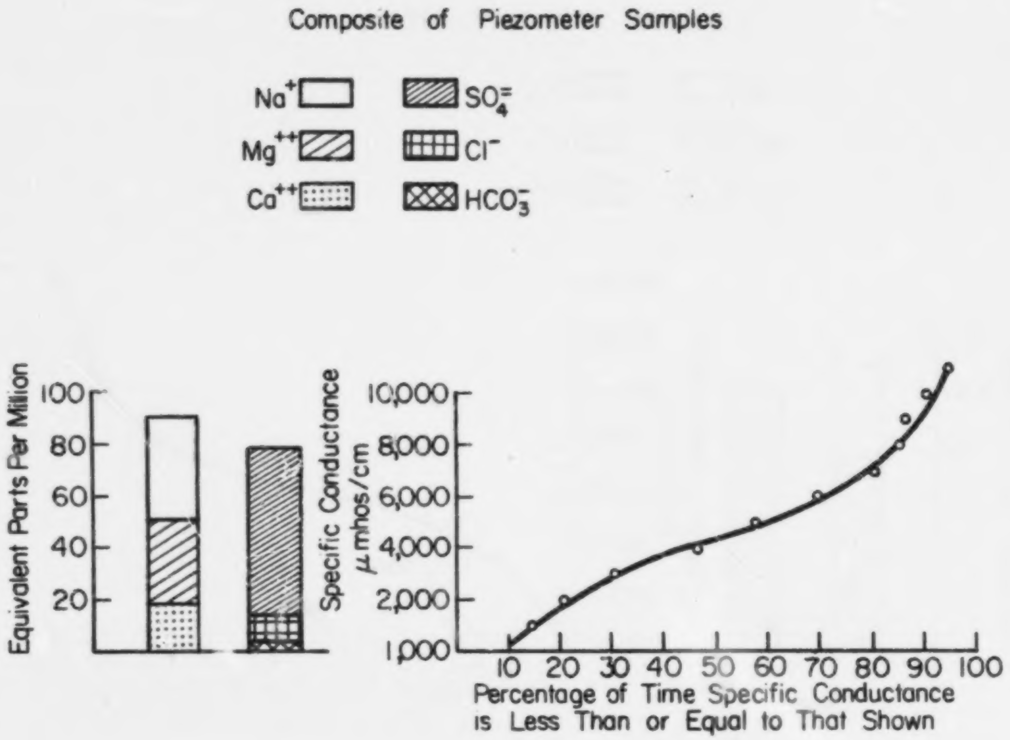


Fig. 36. Bar graph of constituents and frequency diagram of specific conductance of water samples from the near-surface groundwater in the test area.

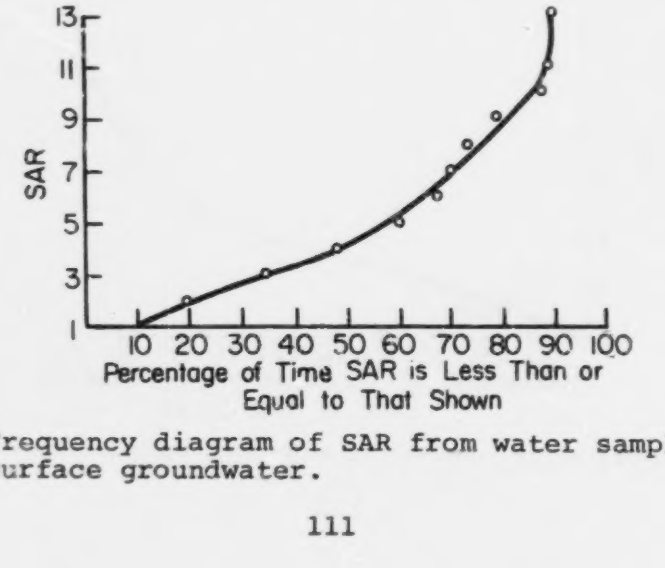


Fig. 37. Frequency diagram of SAR from water samples of near-surface groundwater.

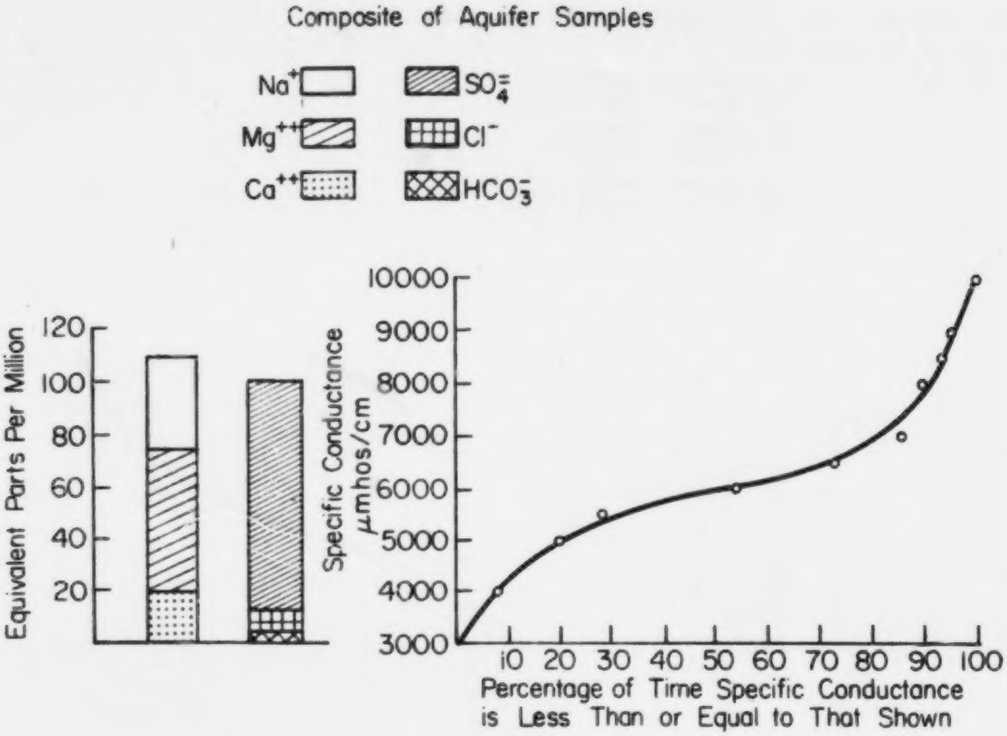


Fig. 38. Bar graph of salt constituents and frequency of specific conductance of aquifer samples in the test area during study period.

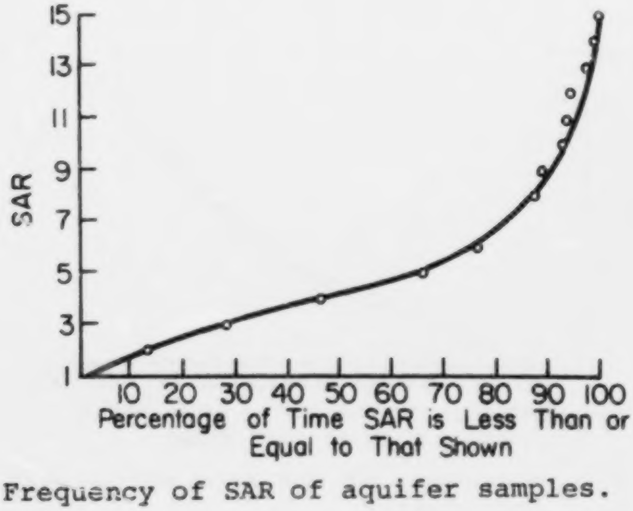


Fig. 39. Frequency of SAR of aquifer samples.

The total contribution of total dissolved solids to the river network approaches 1 million tons annually during periods of plentiful water. During years of low flow, as indicated by Iorns, et. al. (16), this contribution is only approximately half the peak inputs.

The quality samples from the ground water of both the near-surface and cobble aquifers show that sulfates of calcium, magnesium, and sodium represent the bulk of salinity from the Grand Valley, although some significant quantities of chloride salts also are present.

The linear relationships between TDS and EC indicate that the ratio is near 1:1 for the drainage waters. For the surface waters in the Colorado River, the ratio of TDS to EC is between 0.62 and 0.70, which is the ratio usually quoted in the literature.

SECTION IX

EVALUATIONS OF THE CONVEYANCE SYSTEM

Consideration of the water distribution system is an essential part of most salinity control alternatives, which suggests that a broader perspective of system improvement as a salinity control alternative is required. The delivery system in the valley is divided into the canal or ditch subsystem and the lateral subsystem. The division between the two subsystems is based on management responsibility. The canal companies and irrigation districts divert the appropriated water right from the river, transport the water in the canal subsystem, and control the delivery of water through the canal turnout, but they generally assume little responsibility for the water below this point. The canal and ditch subsystem can thus be defined as that part of the delivery network which is controlled by irrigation authorities. The lateral network, extending beyond the turnout from the canal or ditches, is managed by cooperative agreements between the individual users served by the turnout. The transfer of responsibility between the two phases should be the equitable measurement and charge for the water at the turnout, but there is little incentive to make this effort with the abundance of water. A notable exception are the turnouts comprising the Water Users Association under the Government Highline Canal, where individual measurements are made and recorded.

Canal System

The canals and ditches in the Grand Valley, shown in Fig. 40, are operated and maintained by the respective organizations mentioned earlier. Discharge capacities at the head of the canals range from above 700 cfs in the Government Highline Canal to 30 cfs in the Stub Ditch and diminish along the length of each canal or ditch. The lengths of the respective canal systems are approximately 55 miles for the Government Highline Canal, 12 miles each for the Price, Stub, and Redlands Ditches, 110 miles for the Grand Valley system, and 36 miles for the Orchard Mesa Canals. Individual aspects of the canal system are discussed below.

Operation

The management of the canals and ditches in the area varies between canals, as well as with changes in the water supply.

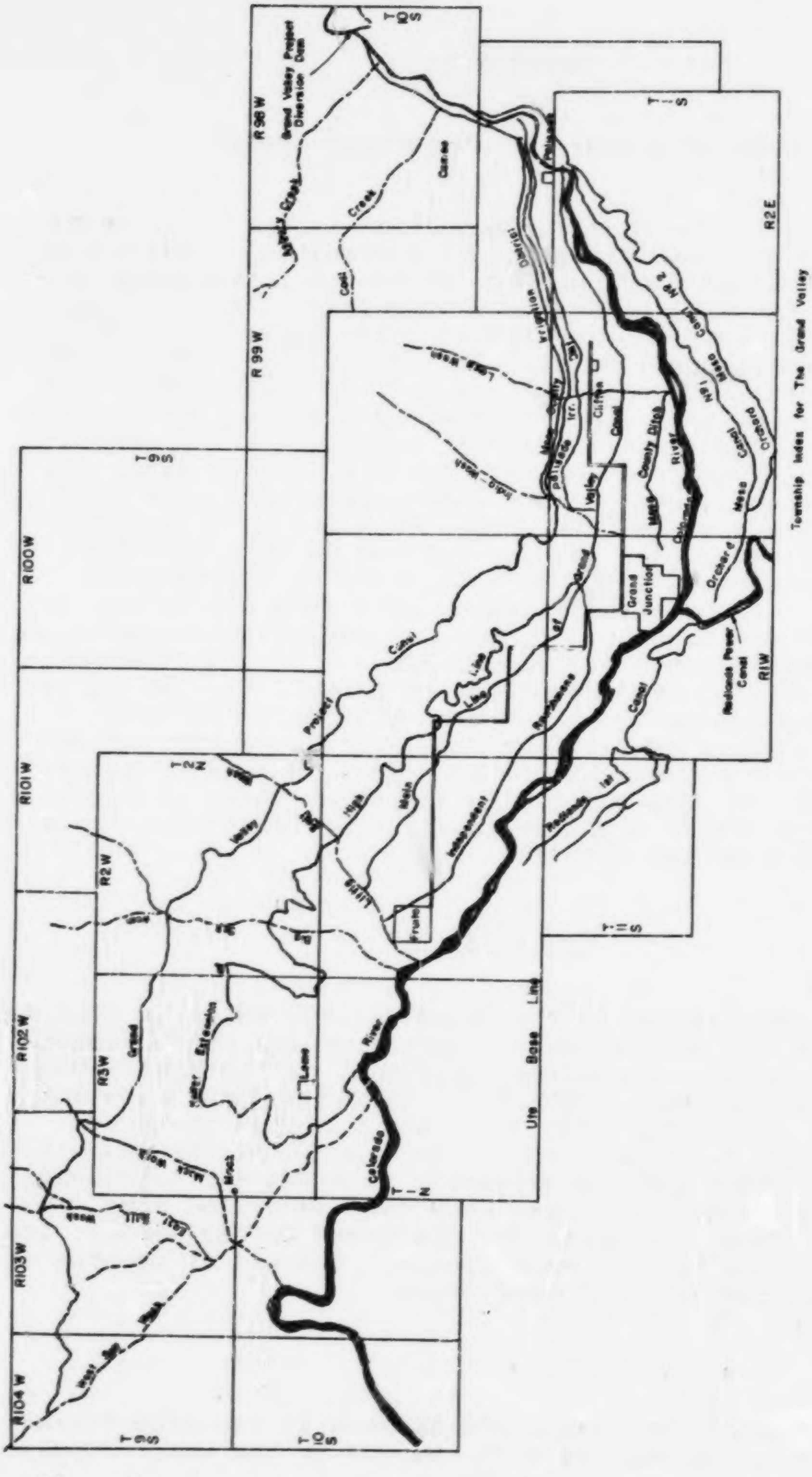

Township Index for The Grand Valley
Grand Valley Project Diversion Dam
Grand Junction
Fruita
Loma
Mack
Colorado River
Redlands Power Canal
Orchard Mesa
Ute Base Line
Highline Canal
Government Highline Canal
Palisade
Clifton
R104W
R103W
R102W
R101W
R100W
R99W
R98W
R3W
R2W
R1W
R2E
T1N
T1S
T2N
T9S
T10S
T11S

Fig. 40. Grand Valley canal distribution system.

For example, it was noted earlier that during periods when river flows become small, restrictions are placed on the diversion into the Government Highline Canal. This is possible because the flows are measured and recorded at each individual turnout in that system, and it is required since their water rights are junior to others. On the other hand, in most instances along the other canals measurements are not made because little shortage is experienced. Another practice used extensively in the region is the regulation of canal discharges at points in the system by varying the amounts of spillage into the natural wasteways and washes. Neither of these practices - inadequate flow measurement and canal spillage - is conducive to salinity control.

The dilemmas being faced by irrigation officials are numerous, but can be traced to one factor. When the demand for irrigation was realized and the canal alignments located, the expected demand for water was based on the total area of land under the canal. However, when the acreages of roads, homes, phreatophytes, etc., are deducted, the water available for each acre is significantly increased. For example, under the Grand Valley Canal are 44,774 acres of which only 28,407 are irrigable. Consequently, instead of having a water duty (annual volume of water diverted from the river per unit area) of 5.76 acre-feet per acre, there is more than 9 acre-feet per irrigable acre. The result is a two-fold problem:

(1) With the excess of water available to the irrigators, it is more economical to be wasteful because failure to provide adequate water to crops during critical growing periods can affect yields more than an over-irrigation.

(2) The history of development in the western United States has always shown water to be a valuable commodity to an area and as such, the rights one has are to be protected since the rights not historically diverted are lost. Consequently, the Grand Valley must divert its rights for fear of losing them.

In short, it is not the practice of agriculture to be wasteful, but the laws regulating the use of water dictate that a user either be wasteful or give up a valuable right.

Canal Seepage

The initial phase of this study involved the determination of the seepage rates from the canals and laterals in the test areas (Area I, II and III). The ponding technique was employed to assure reliability of the results. The first tests were conducted on all canals in Area I except the Grand Valley Canal. The lengths evaluated included a 2.6 mile section of Stub Ditch, 2 miles of Government Highline Canal, 1.9 miles of Price Ditch, and 2.2 miles of Mesa County Ditch. In addition, the tests were made along the 0.5 mile length of the Redlands First Lift Canal in Area III. The 0.15 mile length of Grand Valley Canal in Area II was not evaluated because of the high seepage losses being evident. Also, the construction costs for dikes and tests in relation to the costs of the lining in Area II would have resulted in the testing being more expensive than the lining. A summary of the test results is shown in Table 18, indicating only moderate seepage rates in Area I and a relatively high rate in the Redlands First Lift Canal. The average seepage rates were approximately 0.15 ft^3/ft^2/day (cfd) in the Stub, Price, and Mesa County ditches; 0.25 cfd in the Government Highline Canal; and an average rate of 0.40 cfd in the Redlands First Lift Canal.

Although canal size and depth to the water table may be significant factors influencing seepage rates, the results seem to contradict those of previous investigations. The water table depths in the area of the Stub Ditch, Government Highline Canal and Price Ditch are similar, but the large canal has a noticeably large seepage rate yet it is much more affected by the shale. Nonetheless, it seems justified to conclude that seepage rates in the Grand Valley canals probably vary between 0.15 and 0.40 cfd. Extending these results to the entire valley, the estimated conveyance losses attributable to seepage probably range between 25,000 and 65,000 acre-feet annually, which would mean that between 4% and 10% of the annual diversion results in seepage from canals into the ground water system.

Because the influence of the water table would serve to reduce canal seepage, the location of linings in the low-lying areas may not be as effective as in the upper elevations in the valley to the north. In the principal study area, the water table in many places is higher than the bottom of the Grand Valley Canal and the seepage rates would be reduced.

Linings

Based upon the results of the ponding rests, two modifications to the original proposal (Table 19) were recommended and incorporated in the project. The first recommendation was that the lining of the Government Highline Canal in Area I should be constructed on the downhill bank of the

Table 18. Results of ponding tests on canals in Area I and II.

Canal	Pond no.	Length (ft)	Midstation	Avg. Wetted Perimeter (ft)	Seepage Rate (cfd)	Q* Acre-ft Season
Mesa County Ditch	1	1300	6+50	11.81	0.12	8.46
	2	1075	18+37	12.12	0.13	7.78
	3	1367	30+57	12.14	0.12	9.12
	4	1227	43+55	11.20	0.15	9.40
	5	1025	54+82	10.40	0.15	7.13
	6	1316	66+52	12.22	0.17	12.40
	7	1250	77+85	12.42	0.18	12.80
	8	1449	92+85	12.34	0.13	10.62
	9	1184	106+02	12.59	0.13	8.59
					Total	86
Government Highline Canal	1	4925	28+37	54.92	0.25	310.70
	2	5278	79+39	59.18	0.25	358.30
					Total	669
Price Ditch	1	1930	10+67	15.91	0.12	16.67
	2	1960	30+60	16.41	0.13	19.00
	3	2000	50+00	10.01	0.11	19.20
	4	2035	70+17	12.22	0.11	12.40
	5	1865	89+67	14.12	0.16	19.20
					Total	86
Stub Ditch	1	2175	11+62	10.53	0.15	15.60
	2	2150	33+25	12.34	0.13	15.60
	3	2600	52+06	10.84	0.15	19.40
	4	2300	81+50	13.50	0.12	17.10
	5	2275	104+37	11.69	0.13	15.80
	6	2375	127+62	10.68	0.22	25.60
					Total	109
Redlands First Lift Canal	1	1213	6+06	15.30	0.45	38.20
	2	1318	19+02	14.38	0.35	31.80
					Total	70

*Based on 200-day season

last mile in the study area. The objective of changing from a complete perimeter lining as originally proposed was to make an evaluation of the effectiveness of the downhill lining in reaches where the canal is located in the shale formations. The second change involved reducing the construction scheduled for the drainage system to two small surface problems in the area and the remainder of these funds be spent on lateral linings. The field data indicated that most drains were performing as intended and not seeping water back into the ground water. The linings which were constructed in the canal system as a part of this project are illustrated by the darkened lengths in Fig. 41. The cost estimates of the original proposal listed in Table 19 can be compared to the final estimated costs tabulated in Table 20.

The Stub Ditch linings consisted of the standard trapezoidal slip form concrete lining, as shown in Fig. 42. The location of the Stub Ditch, which runs to just east of Grand Junction, is along the extreme northern edge of the irrigated area of the valley, characterized by rapid and numerous undulations in the topography, causing the canal alignment to assume a very winding path. As a result, the Stub Ditch is often in close proximity to the Government Highline Canal, as indicated in Fig. 42. The linings in the Price Ditch system in Area I and the Redlands First Lift Canal in Area III were of the same nature (trapezoidal slip form) as the Stub Ditch linings.

The other commonly used type of lining in the area was the gunnite material used for the Mesa County Ditch, as shown in Fig. 43. It is of some interest to note the white covered field in the background in Fig. 43, a good illustration of the surface accumulations of salts resulting from poor drainage. This type of lining has several advantages to the local irrigation companies since they are already equipped to accomplish the work and the limited preparation for the linings does not tie up too many people. This same procedure was also used along the short section of the Grand Valley Canal in Area II and the downhill bank lining of the Government Highline Canal in Area I.

The construction of the small drainage improvements in the project is illustrated in Fig. 44. The figure indicates the utility of such a design for a farming area since it reduces the land area occupied by the open drainage system.

An often overlooked aspect of a lining program is the addition of appurtenances to the canal and the rehabilitation of the system in general. Two examples are shown in Fig. 45,

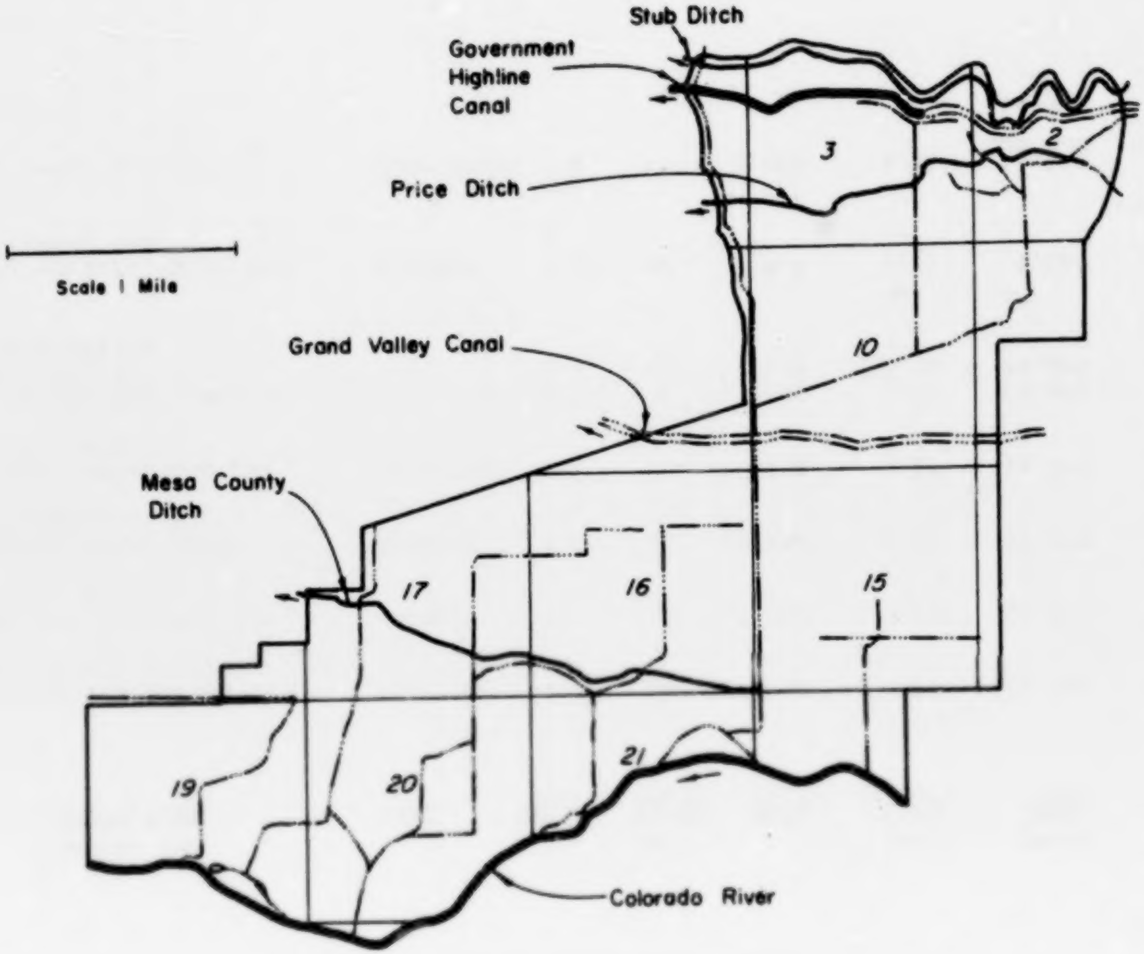

Stub Ditch
Government Highline Canal
Price Ditch
Scale 1 Mile
Grand Valley Canal
Mesa County Ditch
Colorado River
2
3
10
15
16
17
19
20
21

Fig. 41. Location within Area I of the linings that were constructed.

Table 19. Proposed canal lining construction cost.

Map Designation	Company Name Canal Name	Type	Length (mi.)	Perimeter (ft.)	Area (yd²)	Unit Cost ($/yd²)	Total Cost ($)
Area I							
A	Grand Valley Irrigation Co. Mesa County Canal	Gunnite	2.5	15	22,000	3.25	71,500
B	Palisades Irrigation Dist. Price Ditch	Gunnite	2	15	17,600	3.25	57,200
C	Grand Valley Water Users Assn. Highline Canal	Gunnite	1.5	30	26,400	3.25	85,700
D	Mesa County Irrigation Co. Stub Ditch	Slip Form	2	10	11,800	3.25	38,200
E	Grand Junction Drainage Co. Open Drains	Slip Form	6	5	17,600	3.25	57,400
	Other Drains		1.2	10	7,100	3.25	23,000
Area II							
F	Grand Valley Irrigation Co. Grand Valley Canal	Gunnite	.15	22	2,900	3.25	9,500
Area III							
G	Redlands Water & Power	Slip Form	.5	12	3,500	3.25	11,500
TOTAL							354,000

Table 20. Recommended construction program.

Map Designation	Company Name Canal Name	Type of Lining	Length (mi)	Perimeter (ft.)	Area (yd^2)	Unit Cost (\$/yd^2)	Misc. Costs* (\$)	Total Cost (\$)
Area I								
A	Grand Valley Irrigation Co. Mesa County Canal	Gunnite	2.2	14	17,500	3.25	2,100	58,975
B	Palisades Irrigation Dist. Price Ditch	Slip Form	1.9	15	16,720	3.25	1,900	56,240
C	Grand Valley Waters Users Assn. Govt Highline Canal	Gunnite	1.0	15$^+$	8,800	3.50	5,800	36,600
D	Mesa County Irrigation Co. Stub Ditch	Slip Form	2.5	10	14,700	3.25	3,500	51,275
E	Grand Junction Drainage Co.							
	Open Drains	Slip Form						4,000
	Closed DRains	Tile						16,000
	Laterals	Slip Form						110,815
Area II								
F	Grand Valley Irrigation Co. Grand Valley Canal	Gunnite	0.15	15$^+$	1,320	3.50	4,000	8,620
Area III								
G	Redlands Water and Power First Lift Canal	Slip Form	0.5	12	3,500	3.25	1,600	11,475
TOTAL								354,000

*Costs of pre-construction and post-construction ponding tests above amounts in CSU contract, plus costs of installing headgates, etc.

+Downhill bank lining, only.

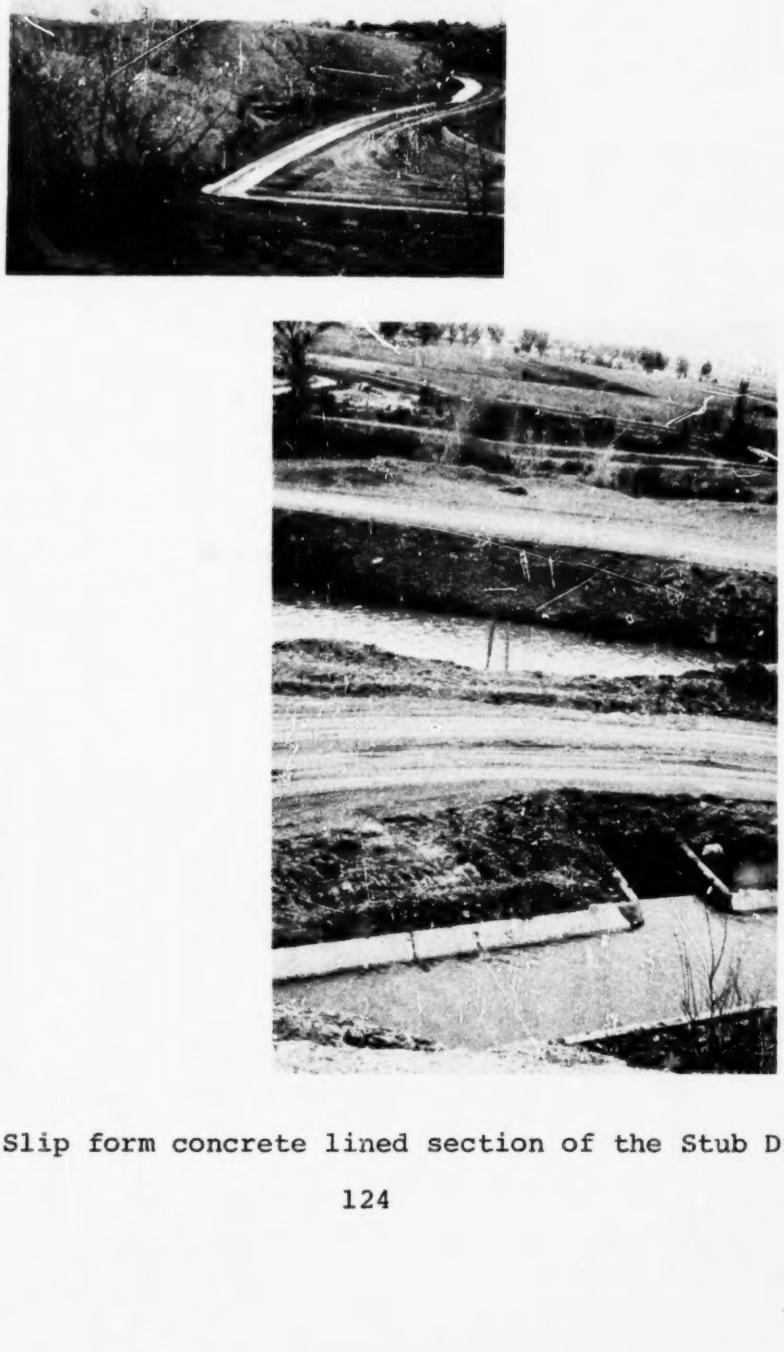
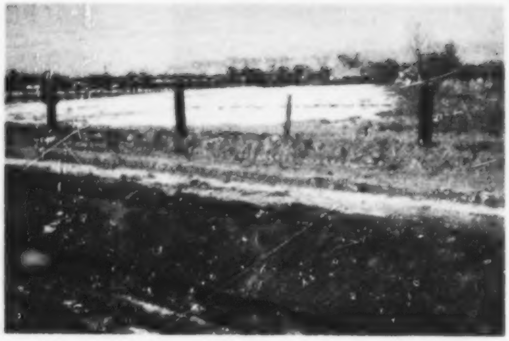


Fig. 42. Slip form concrete lined section of the Stub Ditch.



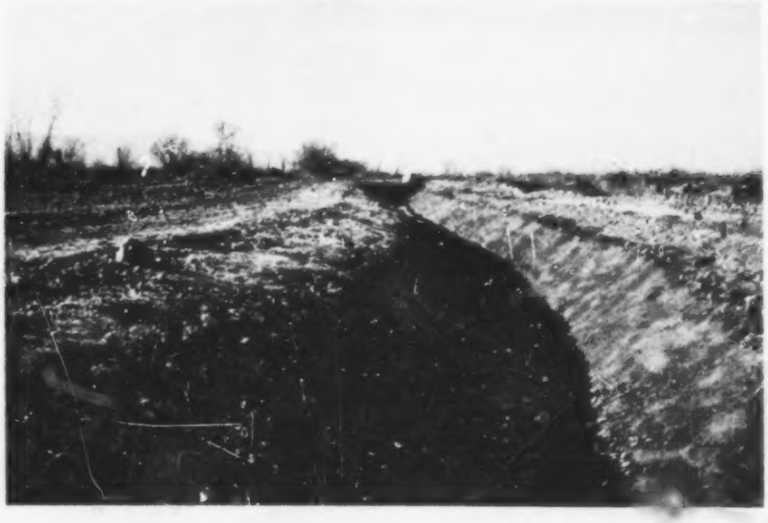


Fig. 43. Gunnite lined section of the Mesa County Ditch.

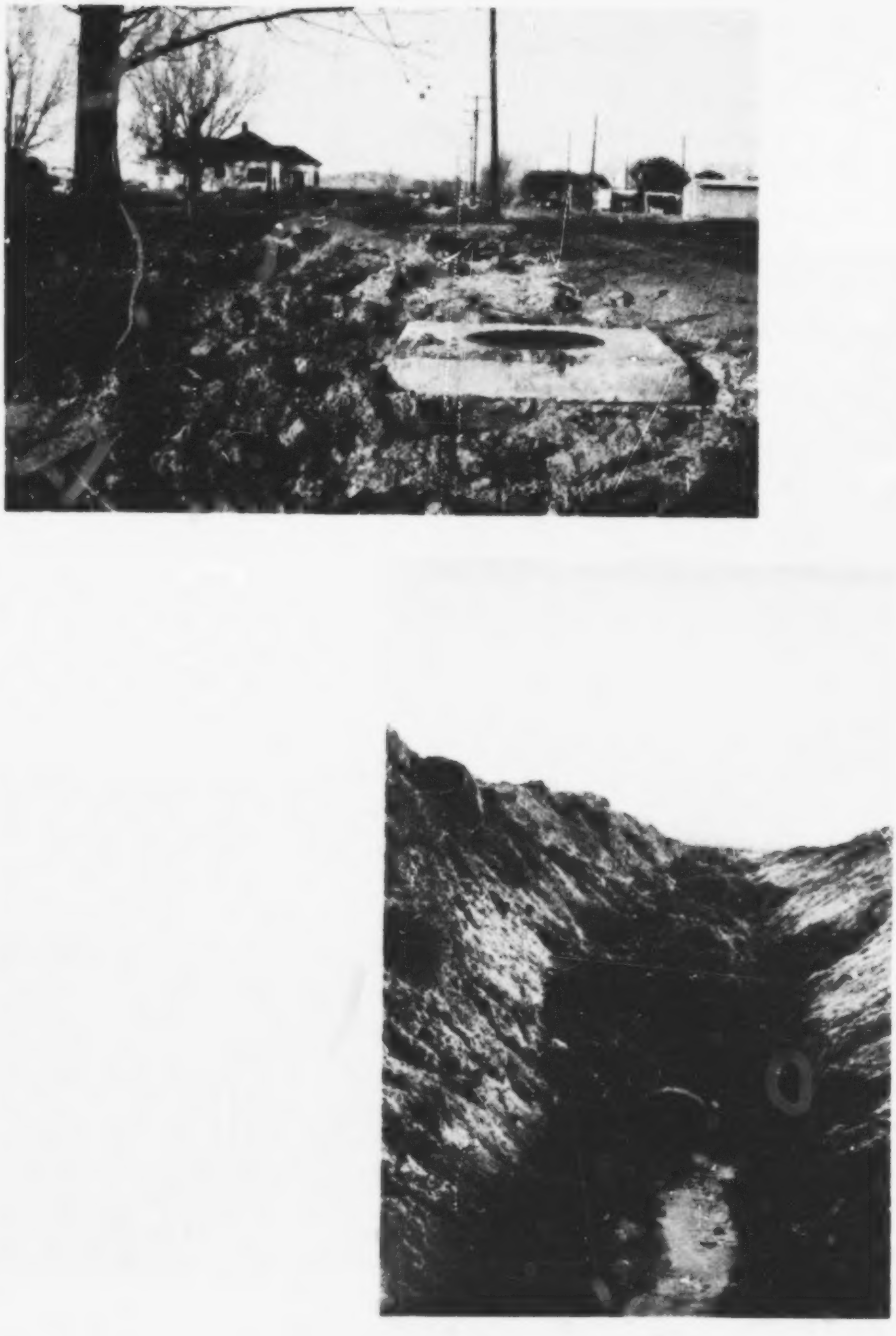
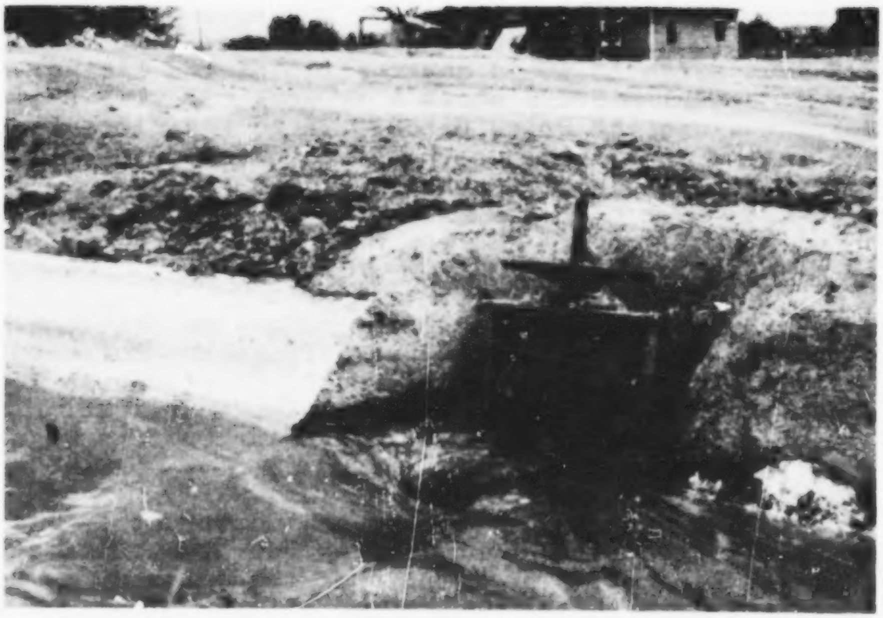


Fig. 44. Tile drain line in the study area.



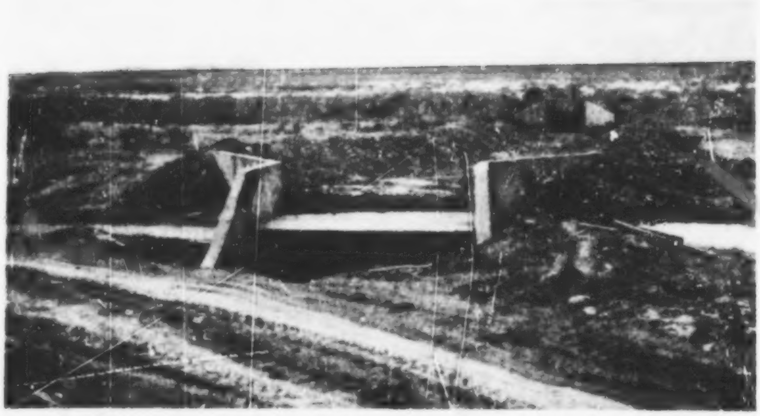


Fig. 45. Special purpose structures built as part of the lining work.

showing first in the lower picture a box-type culvert arrangement to convey surface runoff from adjacent lands over the Stub Ditch to avoid destruction of the lining. The second (upper) picture shows a typical circular slide gate turnout along the Price Ditch. These additions to the canal allow and promote better management of diversions being made into the lateral system.

Results of the Lining

An adequate evaluation of the operation and maintenance benefits attained from the linings was difficult. Correspondence with officials of the Grand Valley Water Purification Project, Inc., most of whom are also serving as local irrigation and drainage officials, has delineated certain benefits resulting from the lining program.

The initial step upon completion of the construction was to conduct ponding tests to determine the rate reduction attributable to the linings. The results of these tests, as well as the comparison with the pre-construction evaluation, are included in Table 21. These results indicate that the linings are not especially effective when the seepage rates are already low.

Table 21. Comparison of seepage rates before and after canal lining using ponding tests.

Canal	Seepage rate before lining (cfd)	Seepage rate after lining (cfd)	Reduction
Stub Ditch	0.15	0.07	46.6%
Price Ditch	0.15	0.07	46.6%
Gov't Highline Canal	0.25	0.13	49%
Mesa County Ditch	0.15	0.03	76%
Redlands First Lift Canal	0.40	0.06	84%

The linings, in addition to reducing the operation and maintenance costs, also result in other direct benefits such as reduced pumping costs. The moderate gradient channels, when running near capacity from April 1 to October 31, experience comparatively few problems with bank vegetation, mossing, and sedimentation. Records and comments from irrigation companies indicate an average maintenance cost per mile of between

$250 and $370 per year in the unlined sections, depending on the canal size. In the intensive study area, the construction will probably result in a total savings of $2500 annually. Although periodic maintenance is always necessary, there are linings ten or more years old located throughout the valley that have as yet required almost no attention. When the canals are lined, the improvements to the delivery system for new turnout structures and measuring devices greatly aid control, distribution, and measurement of water, thereby providing a stimulus to irrigators for more efficient water management.

The local benefits from the linings in many parts of the Grand Valley include factors such as improvements to adjacent lands. In the test area and in a large portion of the valley, the value of land is primarily determined by the expanding urban areas and as such do not greatly depend on agricultural production. Nonetheless, the increased utility of well drained soils is demonstrated in the return to production when water tables are controlled and the construction of basements in homes where they were not possible before.

If the economics of salinity control are examined closely, almost any control method is feasible on the basis of the common benfit-cost ratio. The extension of the concept to a basin scale yields some interesting ideas. The estimated damages expected in Southern California from using an increasingly saline water supply were reported to be about $100,000 per ppm per year (6). If this figure is added to the authors' crude estimate of damages in the remaining lower basin states and Mexico, a conservative value of $150,000 per ppm per year at Lee's Ferry, Arizona is not an unreasonable datum. In the period between 1931 and 1960 and adjusted to 1960 physical conditions in the basin, the annual flow rate at Lee's Ferry was 10,880,000 acre-feet and 8,570,000 tons of total dissolved solids (14). Thus, one ton of salt at Lee's Ferry corresponds to 0.67×10^{-4} ppm and represents a damage of about ten dollars to the lower basin. Other estimates have been around 7 dollars per ton, but have not always considered the indirect costs. In terms of economic feasibility, the cost of reducing one ton of salt can at most cost, assuming a 50 year repayment period at 7% interest, about $138. In order to show a benefit-cost ratio of at least 1, this project should show at least a 4300 ton annual salt reduction from the test areas.

System Improvements

Although the formal results of canal and lateral lining will be established in a later section, several qualitative statements relative to the importance of canal system improvement can be made at this point. The first aspect deals directly with the impact of better system management on the salinity problem. Almost every arid agricultural area depending upon an annually fluctuating water supply can produce evidence to substantiate the fact that during periods of diminished supply, farm production is often higher as a result of better water management on the farm. The explanation for this observation may not lie entirely in the use by the farmer, but also in the attempts to equitably allocate water among the irrigators. Thus, the irrigation company or district is the primary controller when faced with water distribution among demands which totally exceed the supply. Some evidence exists in the Grand Valley area to support the contention that more efficient management of water resulted in significant reduction in salt loading to the river (16). During the years, as shown earlier, when the supply was inadequate to meet demands, the water was "rationed" and more efficient use was made. The conclusion therefore indicates that any presently proposed salinity control alternative to be implemented on a valley-wide scale must involve efficient canal management.

In order to improve canal system management, three types of changes should be implemented: (1) system rehabilitation by lining and installation of effective diversion and control structures; (2) water measurement to each user; and (3) instigation of call periods for demands. The results of incorporating these principles into the operation of a delivery system would be a surplus of water at the river diversion instead of at the canal turnout. Consequently, a large part of the water which is presently flowing as field tailwater or canal spillage could remain in the river. Two questions would need consideration: (1) What incentive is there for canal companies to leave the water in the river and risk losing that portion of their right? and (2) What use would be made of the surplus, and by whom?

Lateral System

As noted previously, the term "lateral" refers to the small conveyance channels delivering water from company operated canals to the cropland. During the early phases of this study, the extent of the lateral system was not clearly defined and the effects of laterals on the area hydrology were underestimated. As a result, considerable reevaluation was made to quantify the aspects of lateral system management.

Operation

When water is turned into the lateral system, it becomes the responsibility of the users entitled to the diversion. Single users served by an individual turnout are not uncommon, but most laterals serve several irrigators who decide among themselves how the lateral will be operated. Most of the multiple-use laterals, which may serve as many as 100 users, are allowed to run continuously with the unused water being diverted into the drainage channels. This practice would be almost completely eliminated if the only water diverted was that quantity appropriated to each acre in the company water rights. The costs that would be passed on to the irrigator for a more regulated canal system would also provide added incentive for more efficient water management practices below the canal turnout. Thus, there would be an indirect economic incentive for better management.

There appears to be a considerable need for system rehabilitation in the form of linings and regulating structures prior to placing restrictions on lateral diversions. The reason is simply that little means of water distribution on an equitable basis below the canal turnout exists. Aside from the canal turnouts themselves, which could be rated individually, no observable means of measurement exists in the intensive study area. Without adding control and measurement structures, it would be impossible to either regulate lateral diversions or distribute the water among users.

Lateral Seepage

Prior to undertaking the evaluation of seepage rates from representative lateral sections, detailed maps of the system in the study area, shown in Figs. 23, 24, and 25, were prepared. From a review of the maps, several lateral sections throughout the area were selected for study. The relatively steep lateral grades in the north-south direction made inflow-outflow measurements the most practical method for measuring seepage rates. Small measuring flumes were installed at the beginning and end sections of each lateral under study, as well as all diversions in the lateral section, or return flows to the lateral section. The discharges were recorded for a period of about one day. The losses were then evaluated from budgeting the water in the isolated lateral reaches.

During the early stages of this effort, it became apparent that the accuracy of the small Parshall flumes were the limiting factor regarding the selection of lateral sections to be studied. The first aspect of the problem was that seepage rates were low enough to be absorbed in the ±2-5% accuracy of the flumes unless lateral lengths of two thousand feet or longer were used. The other problem encountered was that in several laterals a large number of field diversions and field tailwater return flows occurred. In such cases, the number of flumes required introduced considerable uncertainty into the measurements and tended to again mask the seepage losses within the ±2-5% accuracy of the flume. Consequently, the laterals served by the Stub Ditch and Government Highline Canal had to be ignored, and laterals under the remaining canals were carefully selected before undertaking seepage rate evaluations.

The results of the seepage rate measurements for nine lateral sections are tabulated in Table 22. The wetted perimeter of these laterals ranged between three and five feet and was characterized by large amounts of grass and weeds growing in the channel. The capacity of the laterals was usually between one-half and five cubic feet per second, and in most cases, some problems with erosion have occurred as a result of the grade. Some lengths throughout the area had already been lined, but these did not represent a significant portion of the total lateral length.

Results of Linings

Although no effort was made to evaluate seepage rates in the laterals that were lined as part of this study in Area I, it is not unrealistic to assume the same values as found for the canal linings. A typical loss rate of 0.1 cfs per mile would represent a rate in a usual lateral of about 0.5 cfd, or about the same magnitude as earlier studies indicated. Consequently, the lining of most laterals would result in about a 80-90% seepage rate reduction.

A summary of the lateral linings constructed as part of this project is included in Table 23 for comparison with the total estimated lengths in the sections in the test area, a sample of which was listed earlier in Table 14 for T1S, R1E. Obviously, only a small fraction of the system has been improved, but even so the linings probably result in a seepage reduction on the order of 100-200 acre-feet annually. However, it should be noted that the bulk of the linings were constructed above the Grand Valley Canal, where water tables are relatively deep and thus experience somewhat higher seepage rates than would be encountered in areas where water tables are higher.

Table 22. Results of lateral loss investigation.

Canal Name	Gate No.	Study length (ft.)	Length loss (cfs)	Length loss (%)	Loss per mile (%)	Loss per mile (cfs)	Design Discharge* (cfs)
PD	168	2175	0.030	3.8	9.11	0.073	1.00
	164	3620	0.097	3.6	5.27	0.114	2.50
	151	1667	0.048	7.4	23.46	0.152	1.00
GV	95	4910	0.034	1.5	1.61	0.037	2.00
	100	2970	0.020	2.6	4.62	0.315	1.00
	110	5000	0.590	12.3	13.0	0.623	5.00
	120	5280	0.030	1.0	1.0	0.030	3.50
MC	46	2600	0.00	0.0	0.0	0.00	3.00
	70	3540	0.99	18.0	26.82	1.50	6.00

*This value is inlet capacity consequently the design would need to be altered as diversions are made along a length.

Table 23. Summary of the sizes and lengths of laterals lined during the project.

Description	Length in Feet
14" trapezoidal	5,941
12" trapezoidal	11,435
10" trapezoidal	624
*6"x10" rectangular	1,478
*12"x10" rectangular	1,987
12" buried pipe	978
8" buried pipe	2,111
6" buried pipe	950
	25,504
	or
Total	4.83 miles

*First dimension listed in description refers to the bottom width.

The benefits accrued from lining the lateral system in an area like the Grand Valley are essentially the same as described earlier concerning the canal linings. However, because of the vast extent of the lateral system in the principal study area, the effect of the laterals is much greater than canals. As with the canal system, the appurtenances, such as the control and measurement structures, are an integral part of any lateral system improvements. Therefore, the benefits derived from more efficient water management cannot be ignored.

Again, the formulation of salinity control measures must include, in addition to canal system improvements, lateral improvements. In fact, the delivery system in general must be rehabilitated, as well as undertaking improved operation and management practices.

SECTION X

EVALUATIONS OF THE FARM IRRIGATION SYSTEM

Without irrigation, the Colorado River Basin would not support a productive agriculture, but the consequence of irrigation is salinity. Water which percolates into the ground water below the root zone carries with it not only the salts in the irrigation water, but also salts that were dissolved from the soil through which the water passed. In addition, in the ground water basins below the root zones further salt loadings are acquired. The resulting conclusion that the efficiency of on-farm water management is the primary influence on total salt contributions from an area must come as no surprise.

The efficiency of farm irrigation systems varies from locality to locality, and it varies from year to year, or even from irrigation to irrigation during the same year. Although efficiency is influenced by such variables as cost and quality of labor, ease of managing water, type of crops being grown, and the characteristics of the soil, the most important variable is the quantity of water available. If water is abundant, its cost is usually low and there is little economic incentive not to be wasteful to some degree.

The Grand Valley is a good example of a water-abundant area. Its total water rights amount to a diversion of about 5 acre-feet per acre if the area within the irrigated boundaries is considered, but almost 9 acre-feet per acre for each irrigable acre in the valley.

In order to evaluate the pertinent variables for formulating water and salt budgets in the intensive study area of this project, it was necessary to conduct farm efficiency studies. During the first irrigation season, three farms were selected and data were collected concerning the inflows and outflows on each farm. During the second irrigation season, soil moisture measurements were included on four new farms, but the work necessary to install the measuring devices and then to monitor the water use on each farm spread project personnel too thin, and much of this study is inconclusive. During the third and final season, experience with the previous two investigations proved extremely helpful. Two farms were selected from the previous four and considerable effort was made to collect all pertinent data. In addition to the usual soil moisture measurements and inflow-outflow determinations, soil samples were analyzed for salt so that the effect of irrigation on salt movement in the soil profile could be roughly evaluated. Another short-term study conducted was an advance-recession analysis to establish distribution and application efficiencies.

The discussion provided in this section has been primarily limited to the final efficiency evaluation because of its completeness, but the data collected from the other efforts and the experience derived from them was very helpful in the periodic re-evaluation necessary to complete the study.

Description of Farms

The two farms in the intensive study area (Fig. 26) have been referred to as the Martin and Bulla farms, respectively, after the names of the owners whose cooperation made the investigations possible. Both farms irrigate north to south using 1-inch siphon tubes to divert water into the furrows. A more detailed map of each farm, along with the instrumentation employed, is illustrated in Figs. 46 and 47.

The Martin farm, consisting of 9.2 acres of field corn during the 1971 irrigation season, is located between E½ Road and U.S. HWY 6 & 24, and between 30 and 30½ Roads. The 1-inch siphon tubes that flow at a usual rate of about 7 gpm are usually set for a run of about 24 hours, although it only takes 6 to 7 hours to traverse the 1060 feet of furrows. The additional time, while set mostly for irrigator convenience, is used to apply what is thought to be the appropriate quantity of water. The corn crop on the Martin farm, planted about the middle of May, was approximately 15 inches tall by the first of July. In early August, the crop had begun to tassel, and by the 15th of September it had matured enough to be cut and sold for silage.

The Bulla farm, which was irrigated in the same manner as the Martin farm, was comprised of 24.8 acres of corn and 2.7 acres of tomatoes. The length of run in the field varied from 1160 feet in the tomatoes to 840 feet on the western side of the corn field. Again, the set time was 24 hours, but only 5 to 6 hours and 6 to 8 hours were necessary to travel the lengths of the furrows in the tomatoes and corn, respectively. Both the tomatoes and the corn were planted in the middle of May. By the middle of August, the tomatoes had essentially ripened, with the final picking on the 23rd of August.

Both farms lie between the fruit areas in the eastern valley and the sugar beet, grain, and corn areas predominant in the western valley. The region is affected by the growing

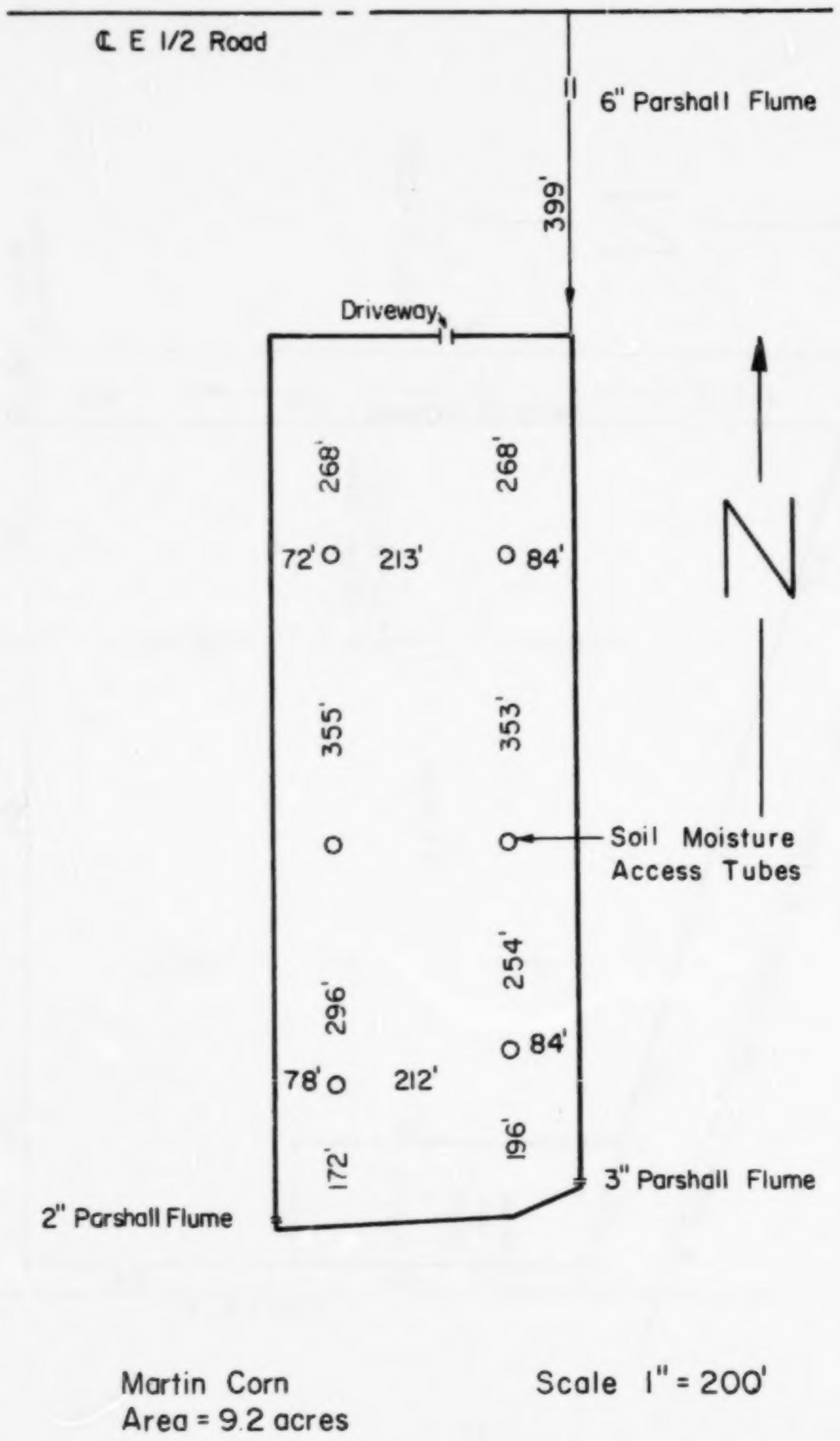

℄ E 1/2 Road
6" Parshall Flume
399'
Driveway
N
268'
268'
72'
213'
84'
355'
353'
Soil Moisture Access Tubes
254'
296'
84'
78'
212'
196'
172'
3" Parshall Flume
2" Parshall Flume
Martin Corn
Area = 9.2 acres
Scale 1" = 200'

Fig. 46. Geometry and instrumentation of the Martin farm.

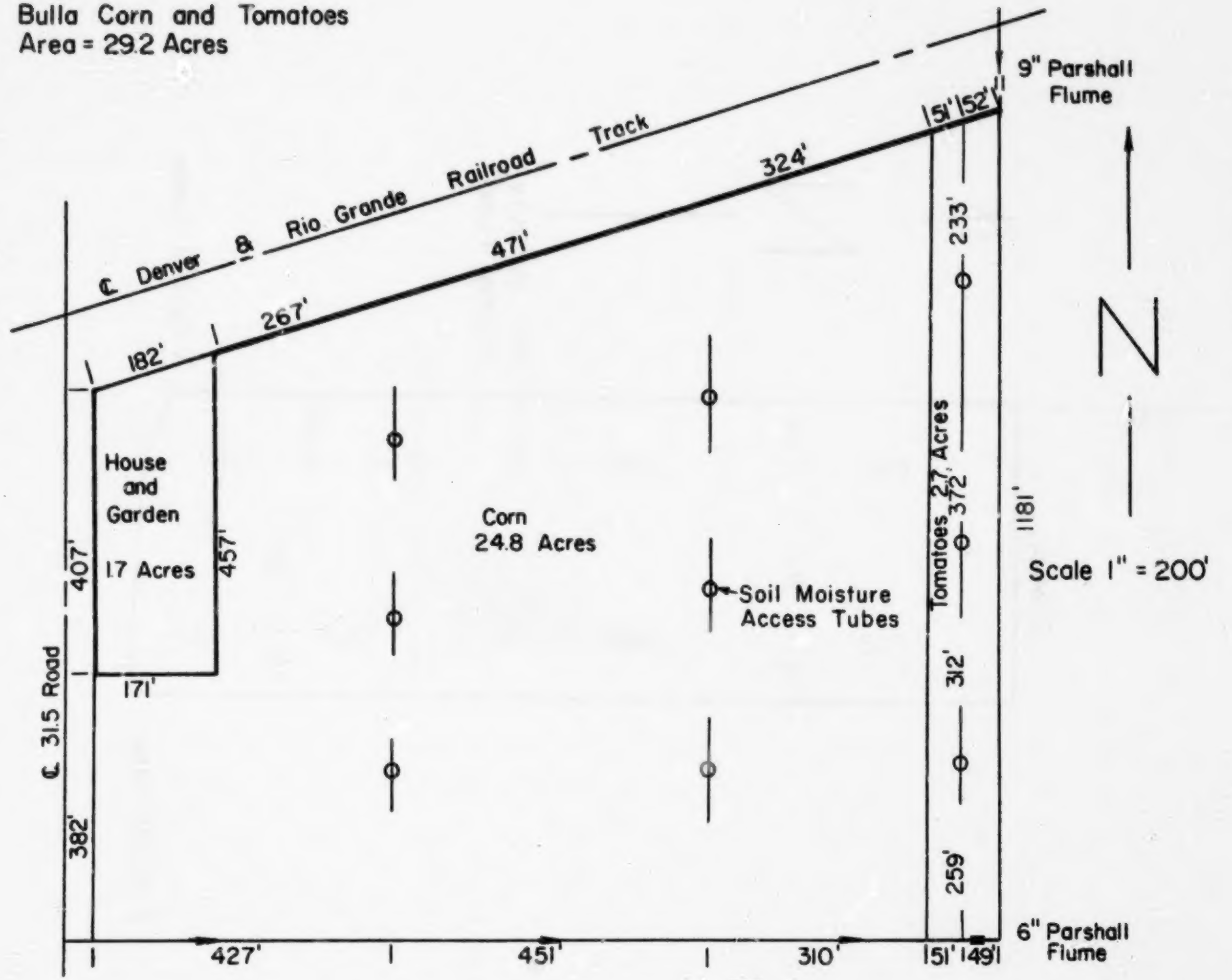

Bulla Corn and Tomatoes
Area = 29.2 Acres
℄ Denver & Rio Grande Railroad Track
182'
267'
471'
324'
51'
52'
9" Parshall Flume
N
Scale 1" = 200'
House and Garden
1.7 Acres
407'
457'
171'
℄ 31.5 Road
382'
Corn
24.8 Acres
Soil Moisture Access Tubes
Tomatoes 2.7 Acres
233'
372'
312'
259'
1181'
427'
451'
310'
51'
149'
6" Parshall Flume

Fig. 47. Geometry and instrumentation of the Bulla farm.

urban center of Grand Junction, where many residents of the area have full time jobs. The farms are usually small, rarely exceeding 40 acres in one unit, and are often managed by renters. The area is comparatively steep in grade and the water tables are high in many places, so that productive agriculture is very difficult to maintain. These factors made the study farms, and in fact the entire project area, attractive to study since the problems are as severe as anywhere in the valley. Thus, if feasible solutions can be determined in an area such as this, which will amend the salinity problem yet improve the agricultural conditions for the water users, success would be assured in the other less complicated problem areas.

Farm Efficiency

Farm efficiency is a general term relating to the effectiveness of an irrigator in managing water from his canal turnout to the end of his fields and the bottom of his root zone. The components of farm efficiency include conveyance efficiency, application efficiency, distribution efficiency, and use efficiency, to mention a few. Conveyance efficiency is defined as the percentage of water diverted from the canal that is actually delivered to the farm. Application efficiency may be defined as the percentage of water reaching the farm that was stored in the root zone by the irrigation. The term distribution efficiency relates to the uniformity of irrigation. And finally, the use efficiency is the percentage of water reaching the root zone that is utilized by the growing crops.

For the purposes of this report, two methods have been selected to measure or indicate farm efficiency. These are:

(1) Application efficiency,

$$E_a = 100 \cdot \frac{W_r}{W_a} \quad \text{......................} (15)$$

E_a = application efficiency

W_r = water either used by crop or stored in root zone

W_a = total water applied to the root zone

(2) Irrigation efficiency,

$$E_i = 100 \cdot \frac{W_r}{W_s} \quad \text{......................} (16)$$

E_i = irrigation efficiency

W_s = total water supplied to the farm

The only difference between the two efficiencies is that the irrigation efficiency accounts for the field tailwater; application efficiency does not.

The instrumentation and methods for evaluating these efficiencies have been discussed in an earlier section, but it may be helpful to the reader to reiterate the procedure in this section.

The inflows to the farms and the outflows were measured with small (6-inch) Parshall flumes equipped with continuous stage recorders. The strip charts were then collected weekly and the discharges determined. The flumes and recorders were checked daily for clock timing and correct stage, and periodically the stilling wells were cleaned so the floats would not stick in the silt deposited in the wells.

To measure the moisture in the root zone of the field, 2-in. diameter aluminum tubes, each 6 feet long, were placed in the field as shown in Figs. 46 and 47. The tubes were installed in the row of the crop so they would not be disturbed by tilling operations. These tubes became the centers for soil sampling and neutron probe measurements. Soil samples consisting of 1-foot core samples to a depth of five feet were taken at a distance of approximately 1 foot from the soil tube. Neutron probe readings were made inside the tube and then correlated with the soil moisture analysis. By proceeding in this manner, it was possible to monitor the soil moisture levels at regular intervals with the neutron probe.

The computation of evapotranspiration from the soil and crop surfaces were made using the Blaney-Criddle method discussed earlier. The values of consumptive use are illustrated in Figs. 48 and 49 for corn and tomatoes in the Grand Valley area. Since these estimates relate to water consumption under conditions where adequate water is available in the root zone, the soil moisture levels were examined to see if these conditions were always met.

The results of the 1971 irrigation season study of the two farms are tabulated in Table 24. These data are for the average field condition, and it should be noted that a leaching requirement has not been included in this analysis. The pre-irrigations in the spring have not been included in this analysis since the project personnel were not able to install the instrumentation until after the crops had been planted.

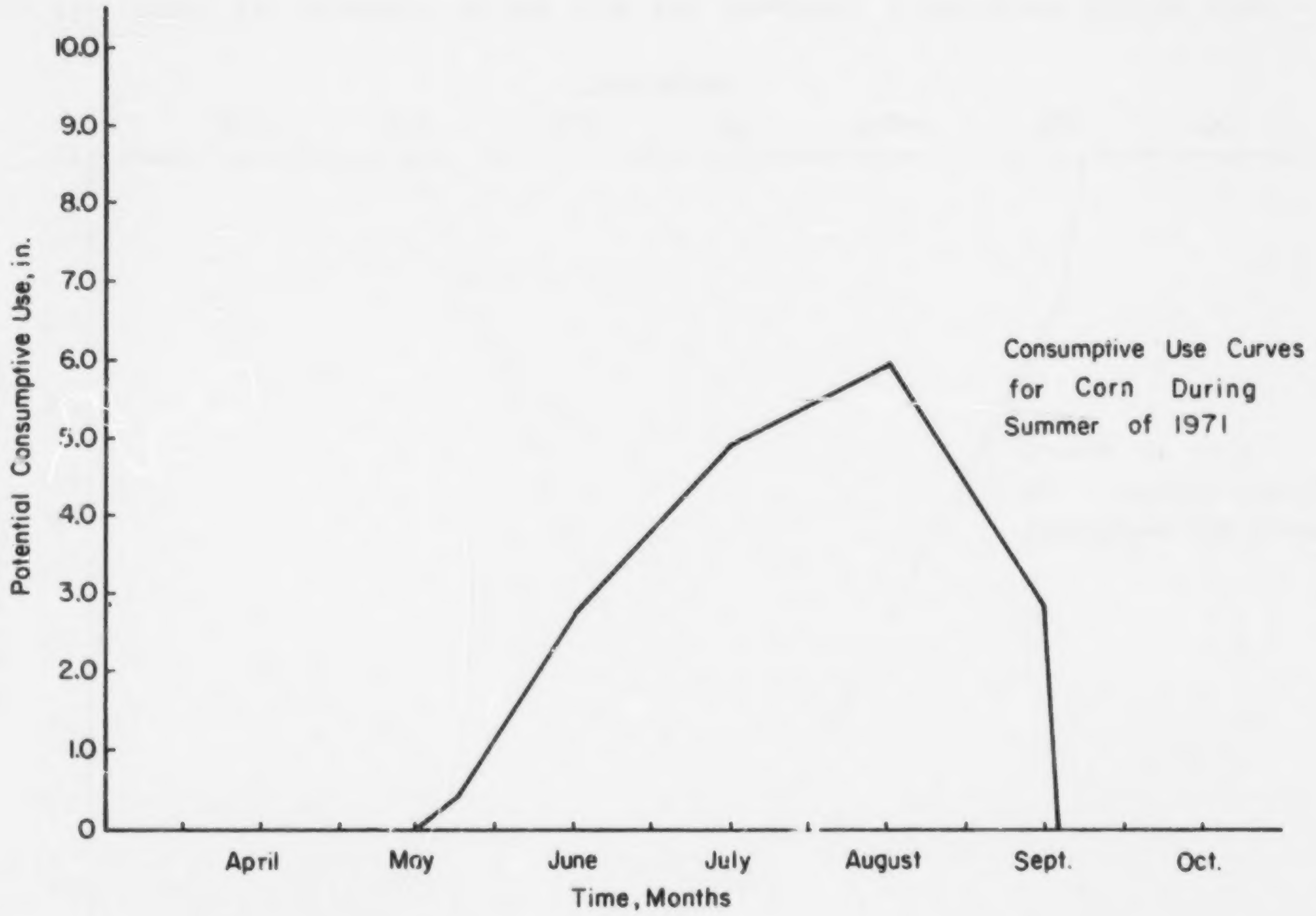


Fig. 48. Potential consumptive use rate for corn in the Grand Valley area.

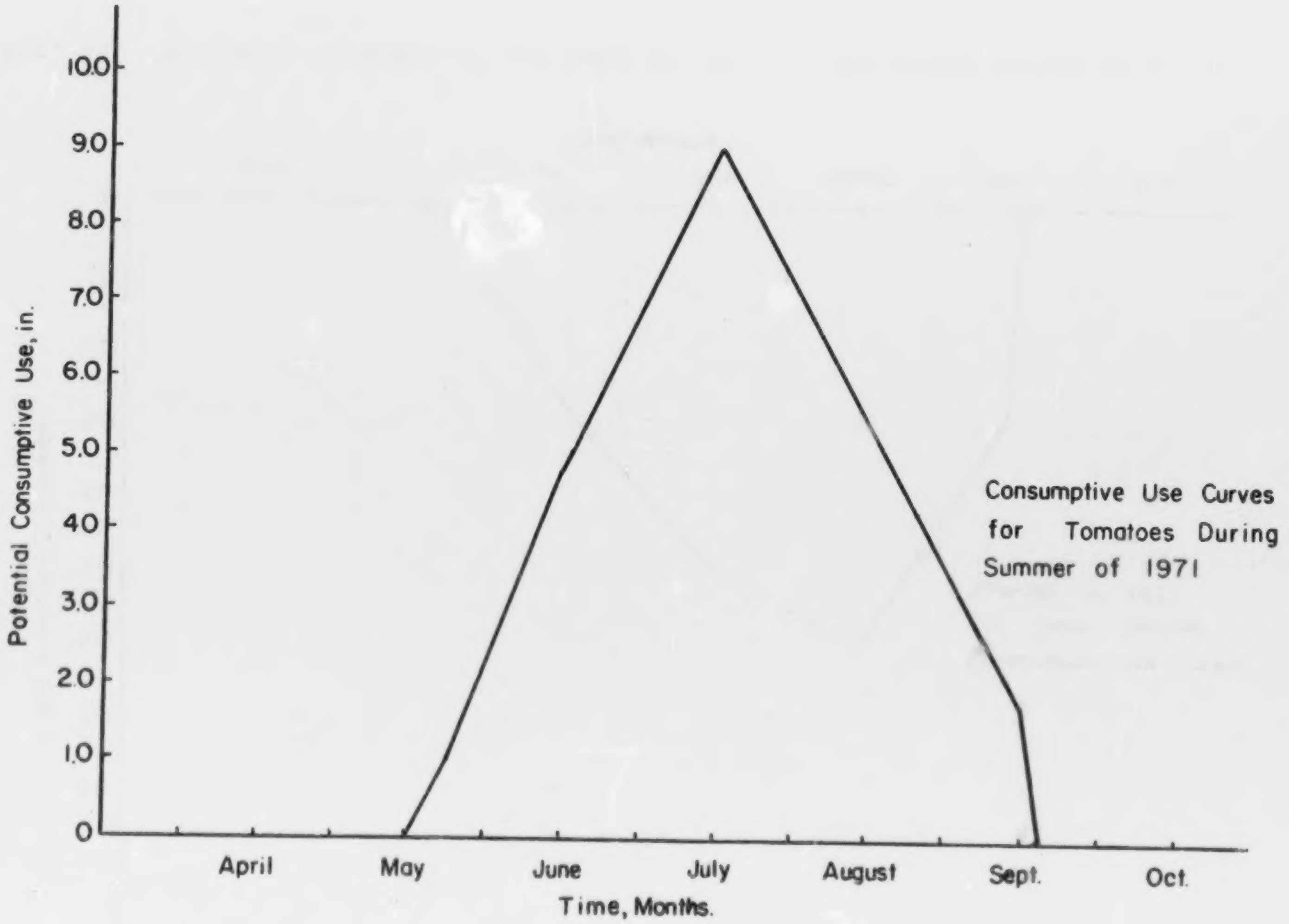


Fig. 49. Potential consumptive use rate for tomatoes in the Grand Valley area.

Table 24. Results of 1971 farm efficiency investigations.

Irrigation Period	Total Inflow (in)	Net Applied (in)	Soil Moisture (in)		Change in Storage (in)	Consump Use (in)	Deep Percolation (in)	Application Efficiency (%)	Irrigation Efficiency (%)
			Begin Period	End Period					
Bulla Tomatoes									
4/16-5/20	22.2	16.05	11.1	18.1	+7.0	0.06	8.99	50.2	36.3
5/31-6/22	9.65	6.08	15.7	16.5	+0.8	3.11	2.89	52.5	33.1
7/20-8/10	9.62	5.66	16.8	17.5	+0.7	4.84	0.12	97.7	57.6
8/17-8/23	8.72	8.44	16.1	17.7	+1.6	0.96	5.88	30.2	29.2
Bulla Corn									
6/9-6/22	5.00	3.53	17.7	20.4	+2.7	0.83	0.0	100.0	70.6
7/7-7/16	7.13	4.02	17.7	17.6	-0.1	1.39	2.73	32.1	18.1
7/20-7/28	8.25	6.02	16.7	18.2	+1.5	1.40	3.12	48.1	35.2
8/4-8/13	8.00	4.79	17.1	17.6	+0.5	1.39	2.90	39.5	23.6
Martin Corn									
6/16-6/26	12.70	8.91	16.5	16.7	+0.2	0.94	7.77	12.8	9.0
7/6-7/29	12.84	6.18	19.2	16.4	-2.8	3.78	5.20	15.8	7.6
8/3-8/13	5.85	2.97	15.2	15.8	+0.6	1.91	0.46	50.9	25.8
8/13-8/24	5.97	3.38	15.8	16.6	+0.8	1.29	1.29	61.9	35.0

The pattern of irrigation does not seem to change a great deal through the season in terms of amounts applied and this makes efficiencies earlier in the irrigation season tend to be somewhat lower than later in the season. The important item in Table 24 is the amount of deep percolation. Under both farm operations, considerable loss was encountered.

Effect of Irrigation Practices on Farm Efficiency

After having measured the efficiencies on several farms during the study period, it was decided to investigate the effect on efficiency that could be expected from different irrigation practices. Since salt loadings are so highly dependent on irrigation efficiencies, the results are an integral part of a salinity control study.

The primary effort in this regard was an advance-recession analysis conducted on both farms near the end of the irrigation season. It should be mentioned that the tests were only conducted once on each farm and thus only indicate the irrigation conditions during the period of the tests. Nevertheless, a qualitative discussion is possible.

The procedure was to select four furrows in which four stream sizes would be diverted. At the inlet and the outlet of the furrow, a WSC 60°V-shaped flume was installed to measure these flows. Then, flumes of the same nature were placed every 100 feet in the furrow between the furrow inlet and exit. The procedure was then to start the flow in the 1-inch siphon tubes and time the advance from station to station along the furrow. When the discharge at the outflow had stabilized, the flow was cut and the recession from station to station was measured. The results have been plotted for the two farms according to the advance curves at various stream sizes in Figs. 50 and 51, and by recession rates in Figs. 52 and 53.

In Fig. 50, the curve representing 27 gpm is noted to fall below the 30gpm curve. The reason for this occurrence is that during the experiment, it was decided that a flow rate between 30gpm and 16gpm should also be run. Unfortunately, the furrow had already been wetted and the results are nonrepresentative. However, the test does indicate the effects of precipitation, or a recent irrigation, or possibly the results of a cutback method of irrigation.

From the advance-recession data, two measures of farm efficiency were evaluated. The first of these is the field

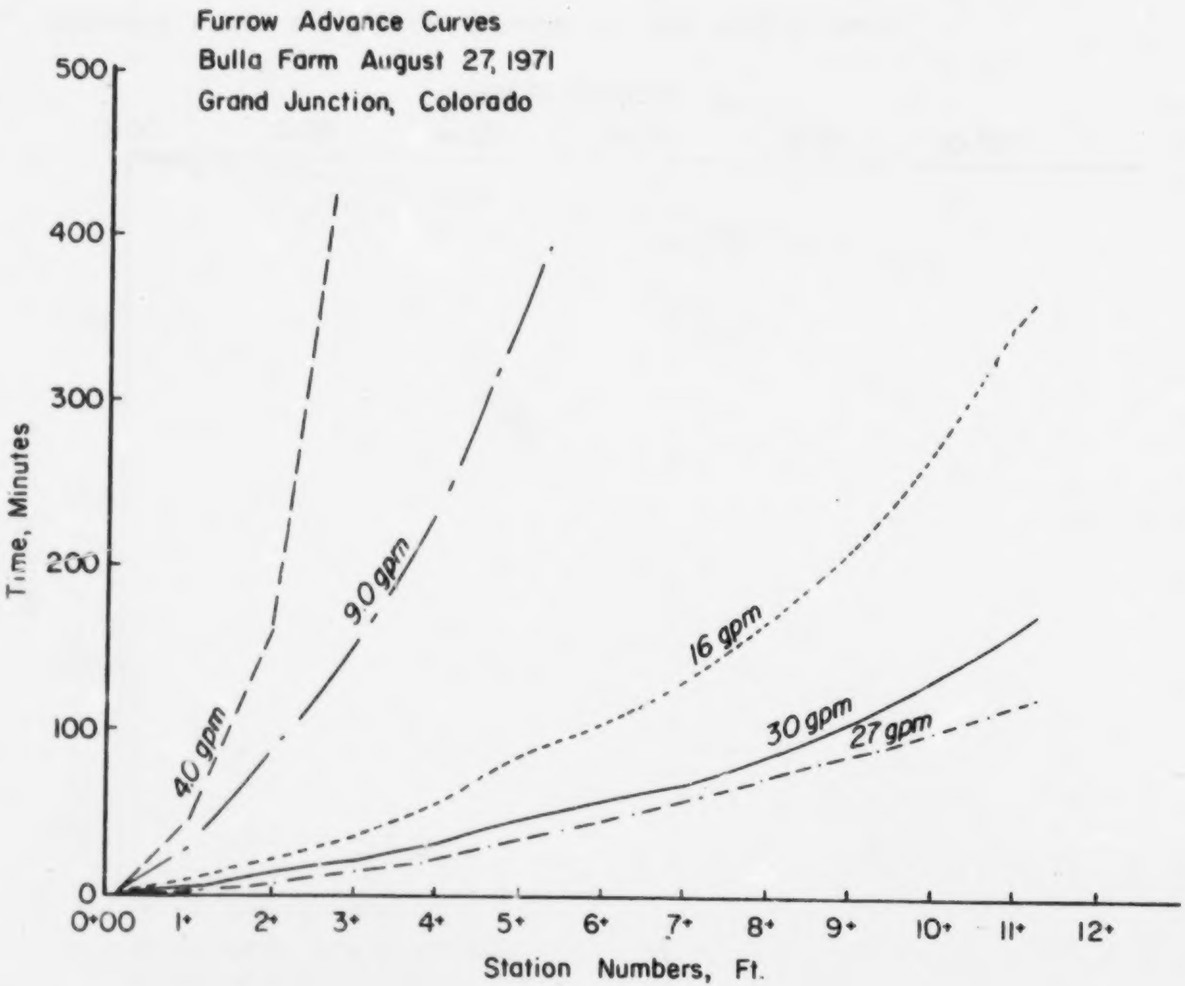


Fig. 50. Advance rate of furrow streams on the Bulla farm.

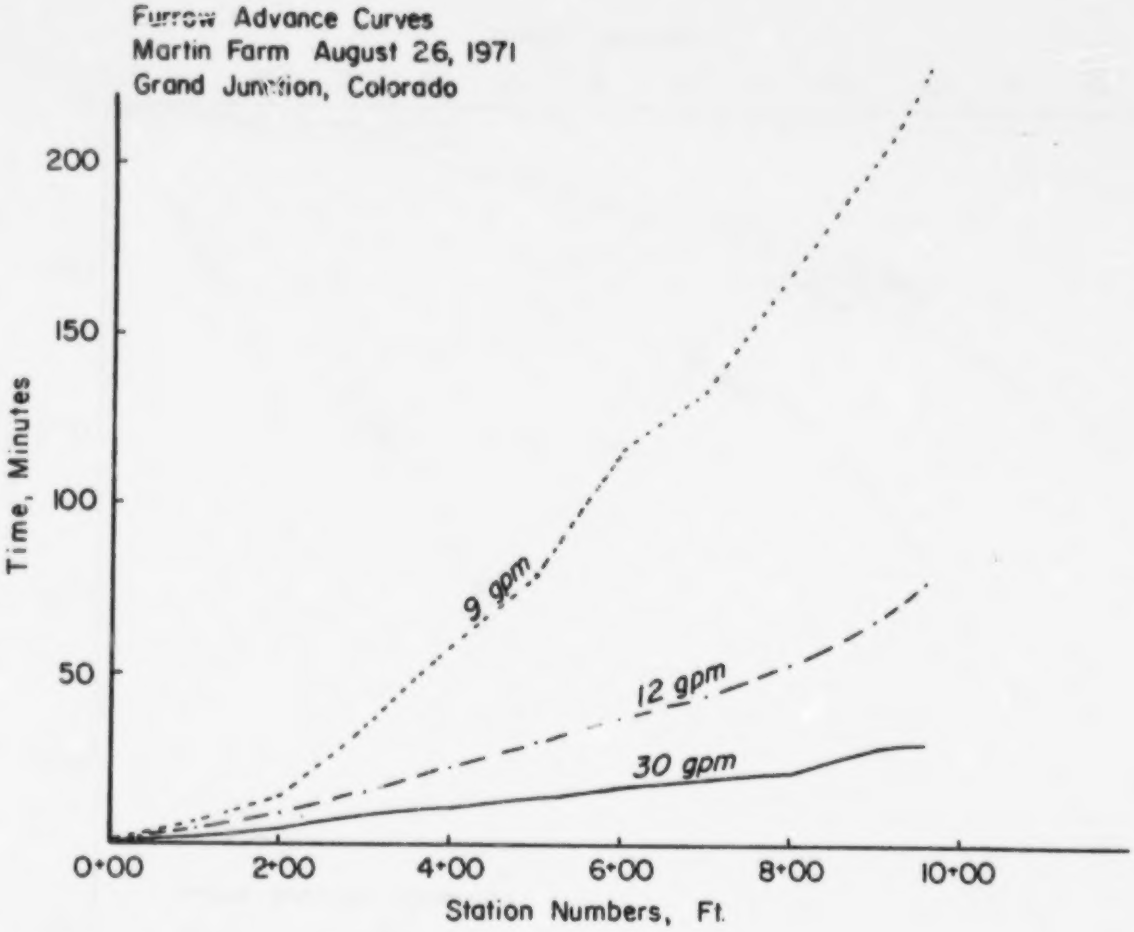


Fig. 51. Advance rates of furrow streams on the Martin farm.

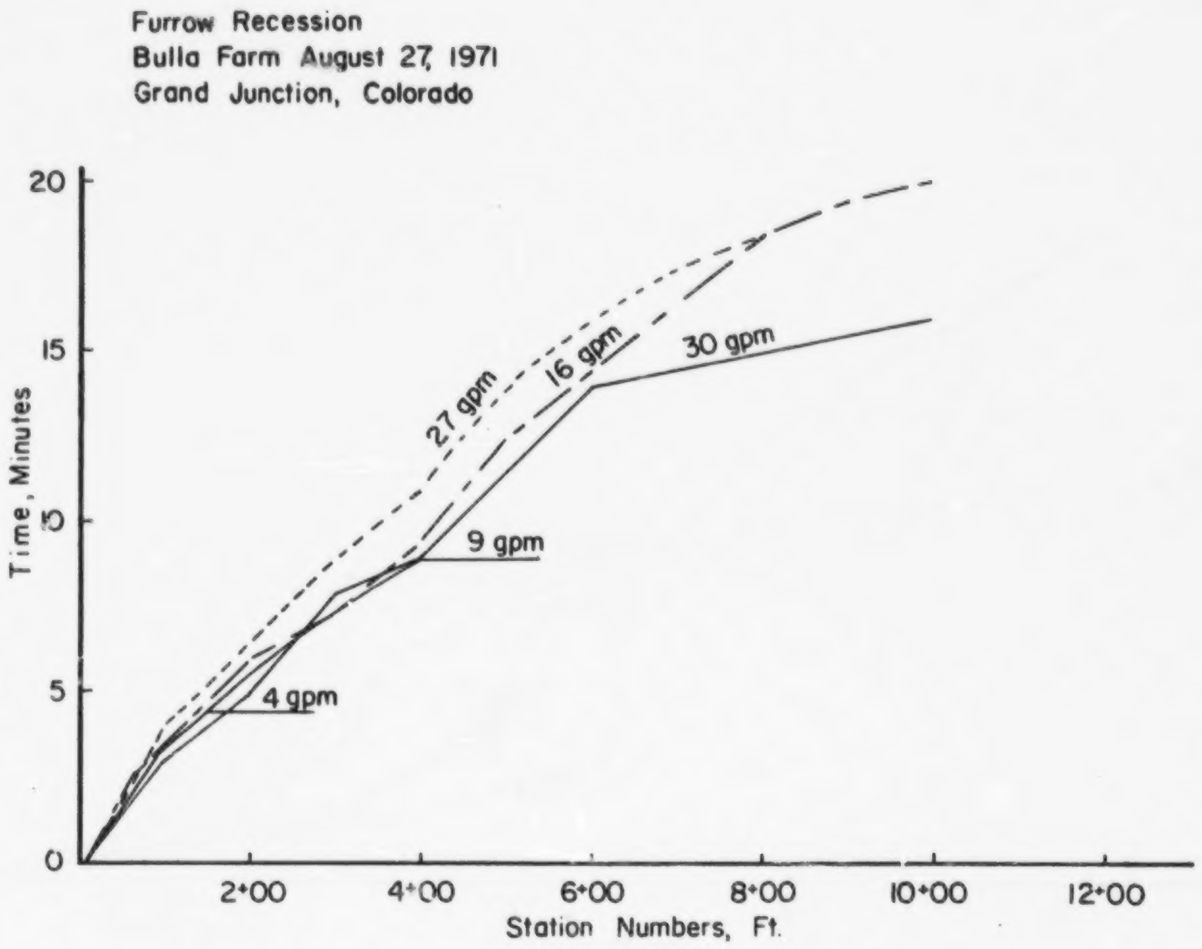


Fig. 52. Recession rates of furrow streams on the Bulla farm.

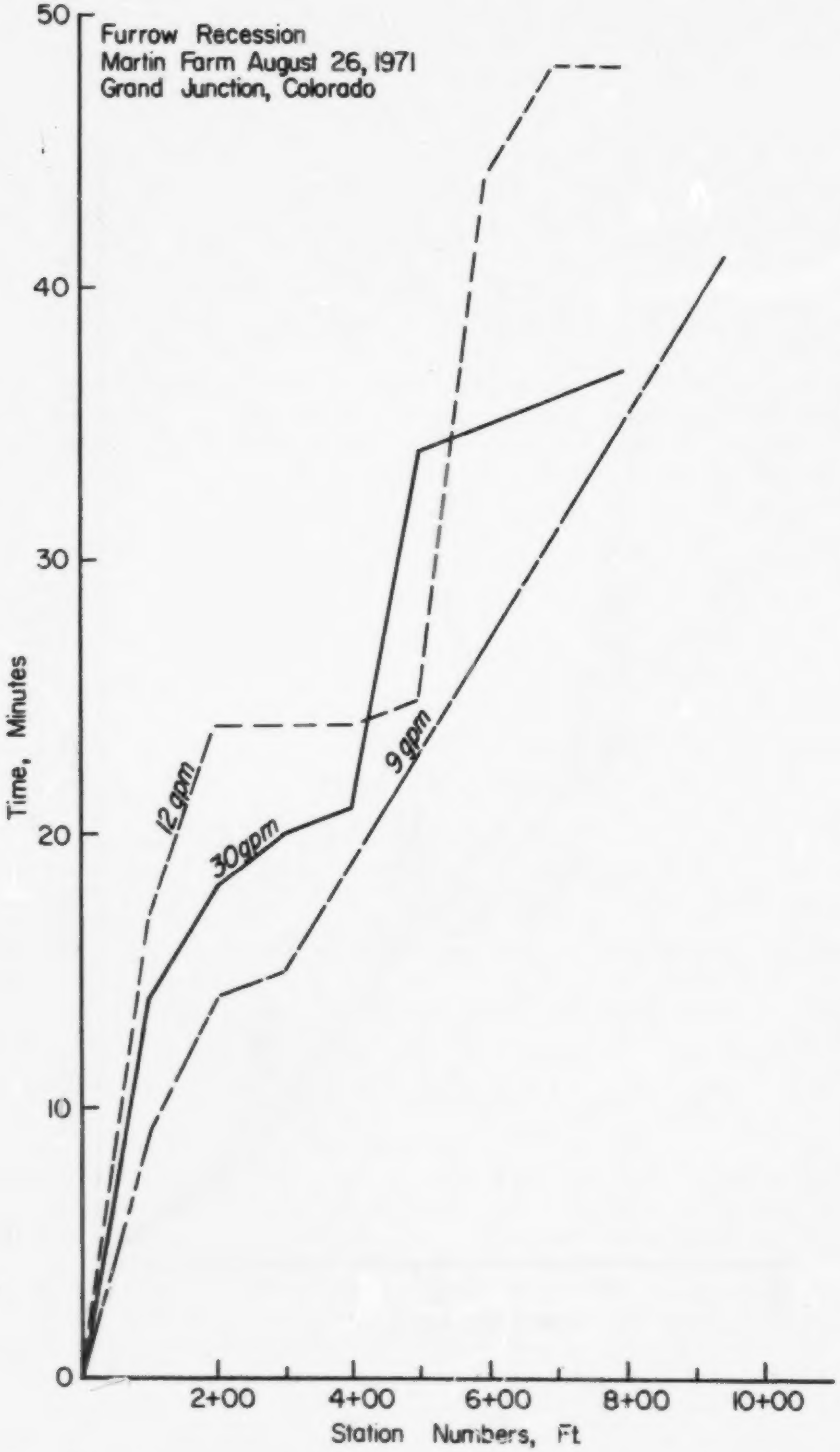


Fig. 53. Recession rates of furrow streams on the Martin farm.

distribution efficiency, which is the percentage of the average depth of water infiltrated in the field to that which is infiltrated at the end of the field:

$$E_d = \frac{D_L \cdot 100}{\frac{D_u + D_L}{2}} \quad \ldots\ldots\ldots\ldots\ldots (17)$$

in which E_d = distribution efficiency

D_L = depth infiltrated at lower end in inches

D_u = depth infiltrated at upper end in inches

The second efficiency is called application efficiency, as in the preceding discussion, except that it is defined as the percentage of the total depth applied that is represented by the average field infiltration:

$$E_a = \frac{(D_u + D_L)/2}{D} \quad \ldots\ldots\ldots\ldots (18)$$

where E_a = application efficiency

$$D = \frac{96.3 \cdot Q \cdot T_a}{\text{AREA of furrow}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

in which T_a = time of irrigation in hrs.

Q = furrow flow rate in gpm

Selected data and analysis have been included in Table 25 for observation of the results. Although some of the data could not be analyzed, it was possible to establish that a uniform application, and in the desired quantity, could be incorporated in the irrigation practice. This would be the first step in a more efficient on-the-farm water management program which would greatly reduce the salinity problem.

Effect of Irrigation on Soil Salts

Many of the soil samples collected to measure soil moisture were also used to measure the salts in the soil profile. Every sample analyzed for salt was measured for pH, specific conductance, calcium, magnesium, and sodium. Rotating sets were also analyzed for complete constituent breakdown. The purpose of performing chemical analyses on the soil samples was to see if the effects of different irrigation practices could be observed on the salts in the soil.

Table 25. Advance-Recession Analysis.

Distribution Efficiencies							Application Efficiencies			
Q (gpm)	Ta (min)	Tad (min)	Ta-Tad	Du (in)	D_L (in)	Ed (%)	Q (gpm)	Ta (min)	D (in)	Ea (%)
Bulla Farm							Bulla Farm			
30	1200	174	1026	13.9	13.1	97.0	30	1200	20.5	66.0
27	1200	122	1078	14.1	14.0	99.6	27	1200	18.4	76.4
30	900	174	726	12.5	11.6	96.2	30	900	15.4	78.3
27	900	122	778	13.6	13.1	98.3	27	900	13.9	96.4
30	600	174	426	10.9	9.6	93.6	30	600	10.3	99.6
27	600	122	478	12.9	12.1	96.6	27	600	9.2	100.0
Martin Farm							Martin Farm			
30	1200	30	1170	4.2	4.1	98.8	30	1200	24.2	17.1
12	1200	77	1123	6.8	6.7	99.4	12	1200	9.65	70.0
30	900	30	870	3.8	3.7	98.6	30	900	18.1	20.7
12	900	77	823	6.6	6.5	99.3	12	900	7.35	89.1
30	600	30	570	3.2	3.1	98.5	30	600	12.1	26.0
12	600	77	523	6.4	6.2	98.5	12	600	4.84	100.0

Two aspects of salt movement in the irrigated soils pertinent to this study are the total salt content of the soil with respect to time and depth, and the activity of sodium. The procedure used to evaluate these parameters was standard soil salt analyses employed by the Colorado State University Soil Testing Laboratory. The soil samples were collected and evaluated for moisture content. Then, the water sample was extracted (saturated extract) by applying fresh water to the soil and then removing it by suction. This procedure has a tendency to collect not only the salts previously carried by root zone moisture, but also to remove some ions from the soil particles themselves. Consequently, the similarity between the salt movements in the soil and these data may be questionable in terms of highly complex reactions that take place in the soil profile during the action of irrigation.

The effect of irrigation in the soil profiles of the two efficiency farms on the total salts has been successfully monitored by measuring the specific conductance of the water sample taken from the soil samples. In Fig. 54, the specific conductance through the soil profile for data collected on the Martin farm is presented. The sample taken on July 6, 1971 probably represents the general condition in a well watered soil in the area, since the specific conductance varies from about 1500 μmhos/cm at the surface to about 3000 μmhos/cm at a depth of 5 feet. This typical soil condition, if indeed it is truly representative, would require a leaching requirement of about 20-30 percent. The samples taken on June 10 and June 16 seem to point out the effect of a pre-irrigation in the spring. The irrigation seems to have been sufficient to distribute the salts in a steadily increasing concentration as the depth in the profile is increased.

The data from the Bulla farm samplings, shown in Fig. 55, have been plotted against time to show the seasonal fluctuation within the various depths of the root zone. All of these lines show the effect of the irrigation between June 16 and June 22, during which time very little water deep percolated out of the root zone. On the other hand, the measurements made on August 3 are shown to be influenced by the high percolation rate during the period of July 20 to July 28.

Two additional graphs, essentially in the same format only indicating the activity of the sodium ion, have been included and are illustrated in Figs. 56 and 57.

During the advance and recession study, the question of water quality degradation resulting from tailwater runoff from croplands was examined. Samples were taken at the head of

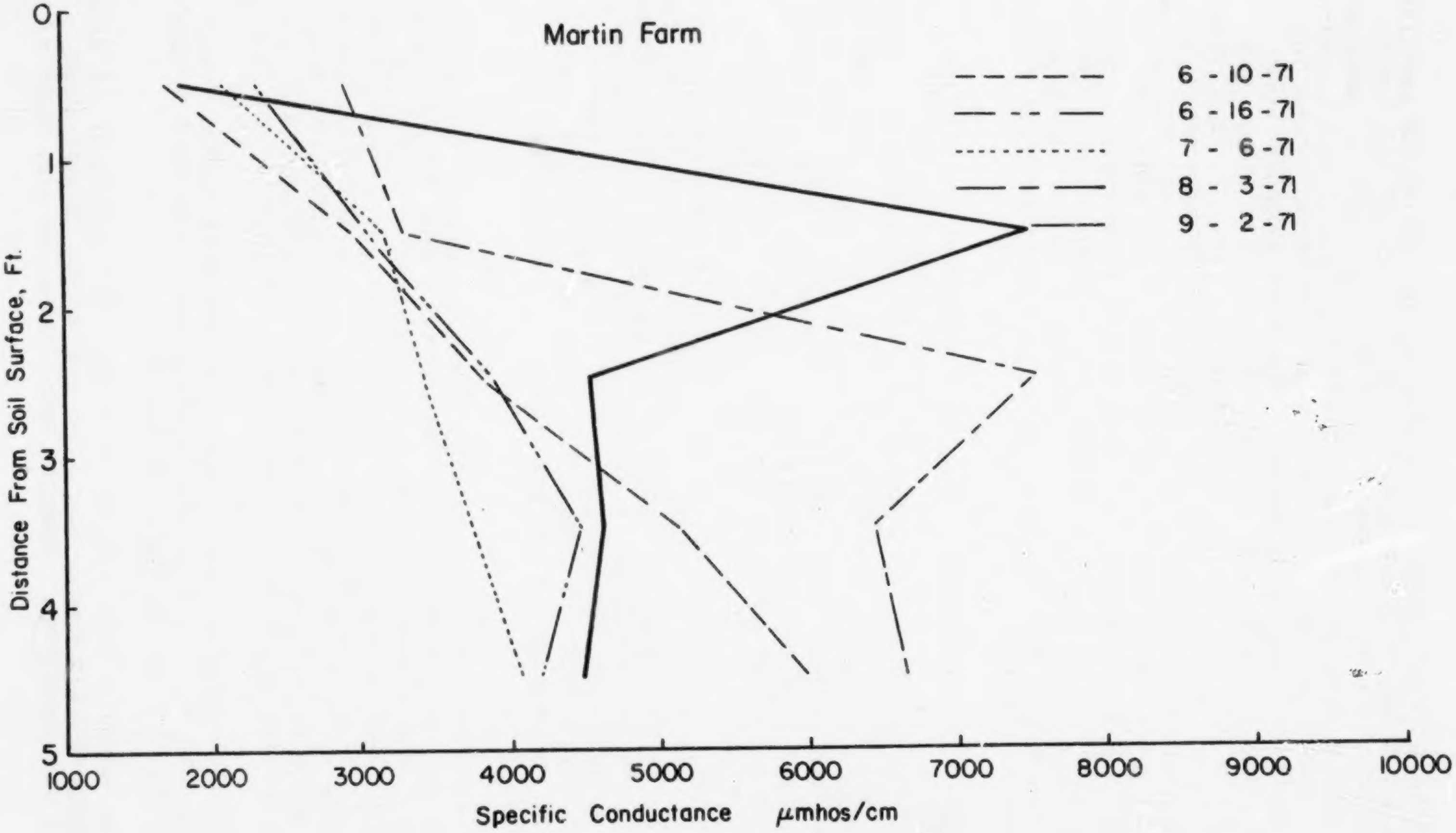


Fig. 54. Specific conductance versus depth plot for the chemical analysis of the soil moisture samples on the Martin farm (samples were saturated extracts).

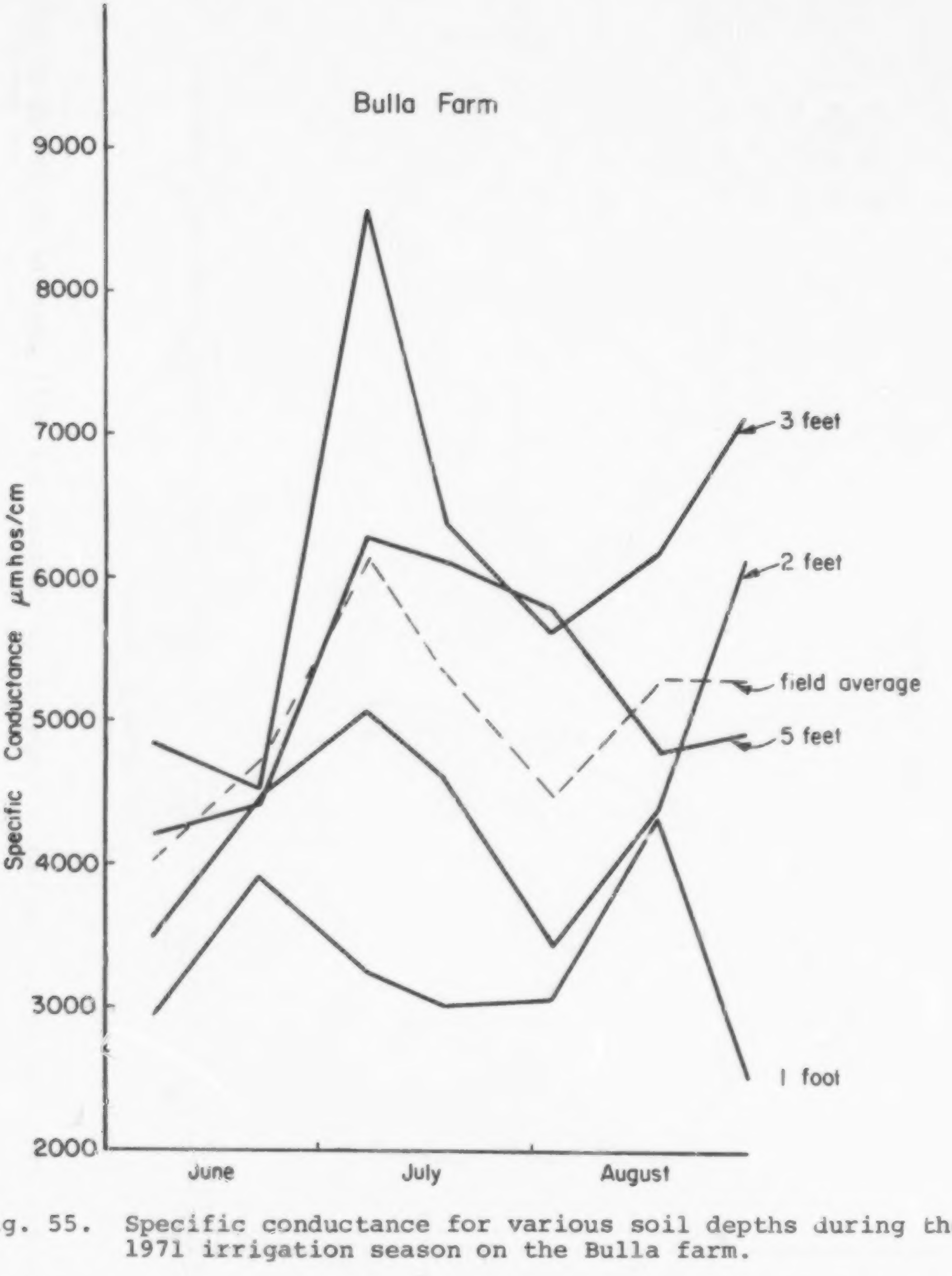


Fig. 55. Specific conductance for various soil depths during the 1971 irrigation season on the Bulla farm.

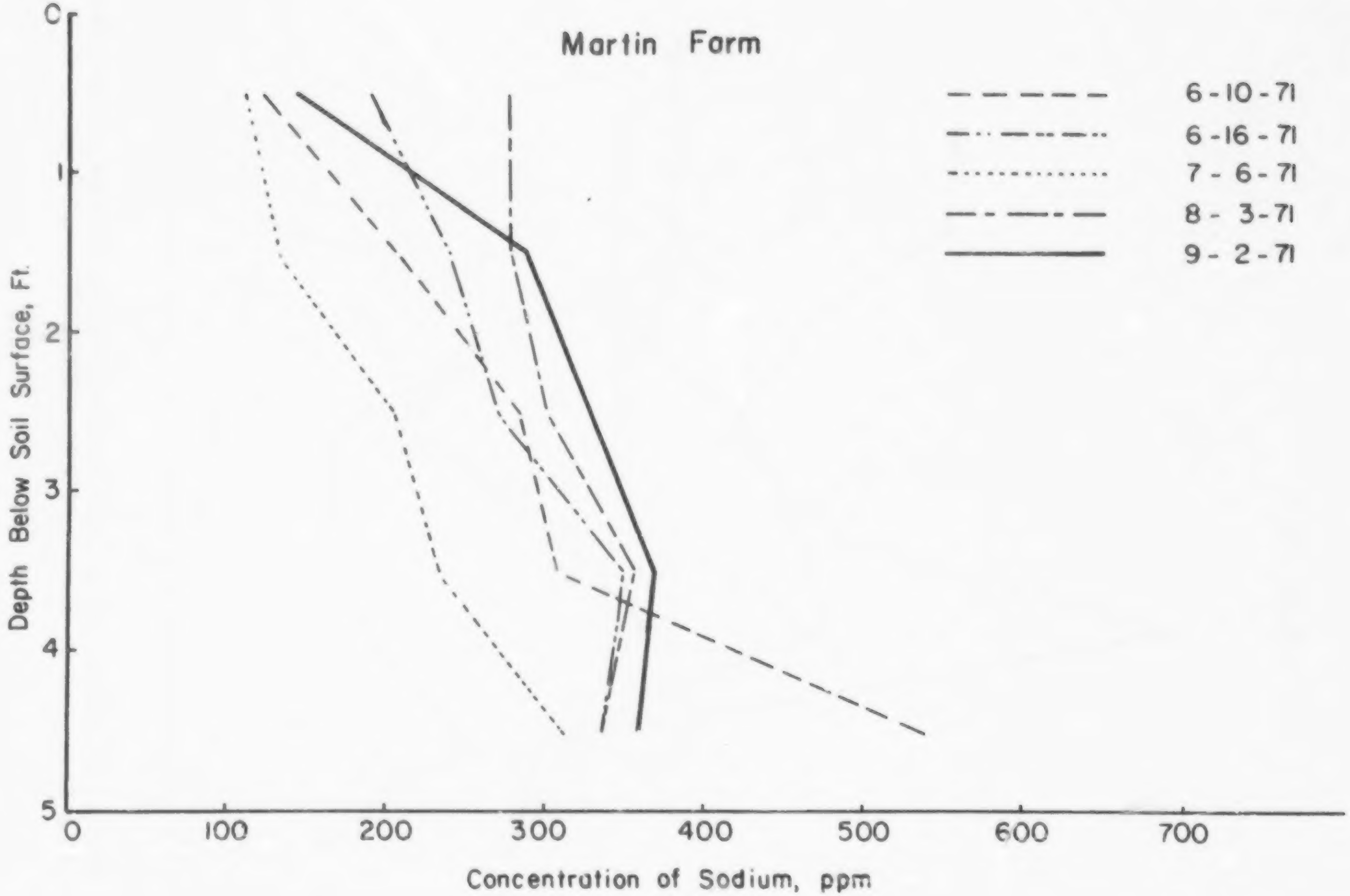


Fig. 56. Distribution of sodium concentration through the soil profile on the Martin farm.

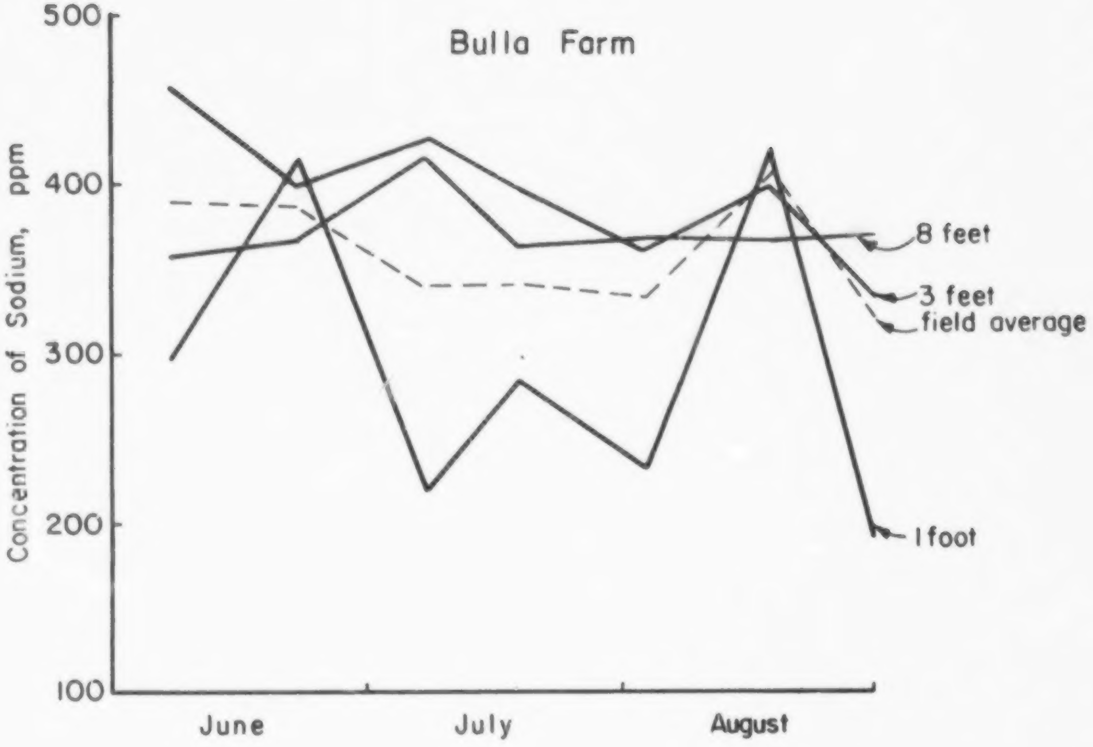


Fig. 57. Change in sodium concentration through the irrigation season on the Bulla farm.

each furrow and then periodically at the bottom of the field. The results indicate very little degradation, while the small amount of salt pick-up vanishes with time as the field tailwater continues to flow.

SECTION XI

EVALUATIONS OF THE GROUND WATER SYSTEM

Because of the salt yielding characteristics of soils and aquifers in the Colorado River Basin, the distribution and quantity of ground waters have a profound influence on regional salinity conditions. In much of the basin, the primary source of ground water is deep percolation losses from inefficient irrigation practices and seepage from conveyance systems. A notable example is the Grand Valley in which a large salt load is added to the system almost exclusively from irrigation return flows. The ground water conditions are also of utmost concern to the local farmers who can make little productive use of lands where the highly saline water tables are too near the surface. It is thus apparent that the control of ground water flows by careful water management, efficient irrigation practices, and adequate drainage is both a local and regional salinity control alternative.

The land on the north side of the Colorado River in Grand Valley drains from north to south along the natural grade. The low lying lands adjacent to the river must convey not only irrigation return flows from these areas, but also the flows from all higher lands to the north. The result is a noticeable decline in agricultural productivity towards the river as the natural drainage capacities are exceeded and a high water table occurs. In this investigation, the scope of ground water examination has been limited to the saturated area between the water table and the top of the Mancos Shale.

The similarity between the intensive study area utilized in this research effort and most of the valley is thought to be quite good. Other investigations in the western valley have established the ground water conditions in that area. The discussion in this section can therefore be centered primarily on Area I. The conclusions regarding salinity management are also thought to be fairly representative of the valley.

Soil and Aquifer Characteristics

An evaluation of the basic characteristics of the subsurface region, such as hydraulic gradients and conductivities, stratification, and strata topography, is an important consideration in examining the ground water system. In Grand Valley, the structure of the substrata makes it convenient to examine the cobble aquifer and the overlying soil individually. The interaction of these two flow regions is probably the most critical factor influencing the design of either a salinity control project or a drainage system. Water in both areas comes primarily from deep percolation from over-irrigation, as well as canal and lateral seepage losses. Between the soil and the cobble aquifers there exists an intermittent clay layer having a very low hydraulic conductivity (0.0001 in/hr), which restricts the flow between the two regions primarily to areas where holes or thin spots exist in the clay layer. Ground water above this confining layer may not be the only source of water in the cobble, since the cobble strata only extends part way up the northerly cross section of Area I.

The holes or thin spots in the confining clay strata may allow either an upward or downward movement of water through the clay layer. When artesian conditions exist in the cobble, upward movement of water into the soil zone may result in local areas of severe waterlogged conditions, with associated visible salinity problems. On the other hand, downward movement into the cobble may occur, with good drainage being evident as the flow in the cobble is much less restricted than in the soil above.

Soil Characteristics

A great deal of work was performed in Area I to establish the characteristics of the soil profile below the water table. The first effort was the installation of the 3/8 inch steel pipe piezometers discussed earlier. During the process of installation, it was possible for the man holding the pipe to feel the changes in soil texture as the pipe was jetted downward. Lenses of small gravel and the periodic clay layer were especially noticeable. Since numerous piezometers were placed throughout the area, it was possible to locate the more obvious strata in the test area. In addition, since it was impossible to extend the pipe beyond the confining clay layer, the upper surface of the cobble aquifer was also located. A typical profile resulting from the logs of this work was illustrated earlier in Fig. 8.

Once the piezometers had been installed, periodic water level measurements were made in each tube, which indicated the pressures through the soil profile. The piezometers, which protruded only a short distance below the water levels in them, were assumed to be good indicators of the water table elevation. In order to give the reader some idea of the magnitude of the changes in the ground water conditions, data prior to the irrigation season, along with that collected during the peak of the irrigation season, have been pictorially represented in Figs. 58 and 59, respectively.

As pointed out previously, the vertical hydraulic gradients in the ground water basin indicate the movement of the water. The piezometer clusters were installed to determine these gradients. The data collected thus far indicate little or no artesian condition in the test area, as was found in the western valley studies reviewed earlier. This would indicate that drainage from the soils is taking place into the cobble aquifer. Thus, the high water table conditions in the area represent an overloading of the natural drainage capacity.

Since the ground water return flows to the river proceed from north to south, the piezometers were also used to evaluate the horizontal hydraulic gradients, which are the driving forces causing the flows to occur. During the two periods illustrated in Figs. 58 and 59, the weighted average horizontal gradients were 0.00899 ft/ft and 0.00939 ft/ft, respectively. The relatively small changes between the two periods, along with the comparison of the magnitudes of vertical gradients, again indicate the primary movement in the soils to be downward.

The piezometers were also utilized to measure hydraulic conductivity according to the method outlined in SECTION VII. The results of this analysis, tabulated in Table 26, show a low permeability in the soils. It has been well established that soil permeability is highly affected by the sodium ion concentration present in the soil solution. It seems justifiable to conclude from the analysis presented in SECTION VIII that the relatively high proportions of calcium and magnesium ions found in ground water samples have resulted in some improvement in the soil structure, thereby causing these conductivities to be greater than in high sodium areas.

Cobble Aquifer Characteristics

The conditions in the cobble strata were monitored during the study with 2-inch wells drilled into the layer. Tests from previous investigations noted earlier, along with limited data from this effort, indicate an average value of hydraulic conductivity on the order of 40 inches per hour, or about 4000 times as permeable as the soil and about 400,000 times as much as a typical value for the confining clay stratum. The drillers log for the 1951 test

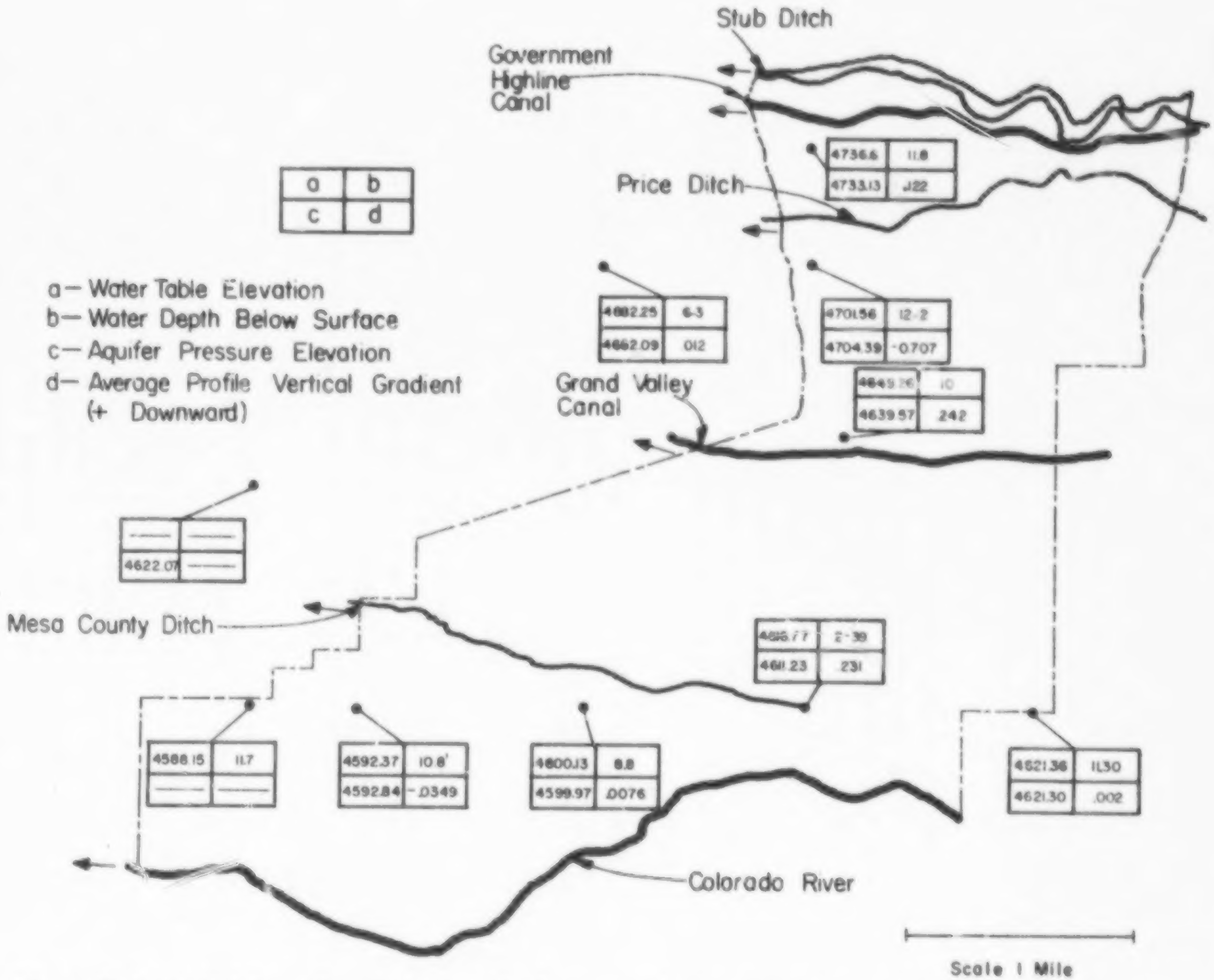

Stub Ditch
Government Highline Canal
Price Ditch
Grand Valley Canal
Mesa County Ditch
Colorado River
a
b
c
d
a— Water Table Elevation
b— Water Depth Below Surface
c— Aquifer Pressure Elevation
d— Average Profile Vertical Gradient (+ Downward)
4736.6
11.8
4733.13
.122
4682.25
6-3
4682.09
.012
4701.56
12-2
4704.39
-0.707
4649.26
10
4639.57
.242
4622.07
4616.77
2-39
4611.23
.231
4588.15
11.7
4592.37
10.8'
4592.84
-.0349
4600.13
8.8
4599.97
.0076
4621.36
11.30
4621.30
.002
Scale 1 Mile

Fig. 58. Water table elevations, below surface depths, average vertical gradients, and cobble pressures for selected stations in Area I during March 1971.

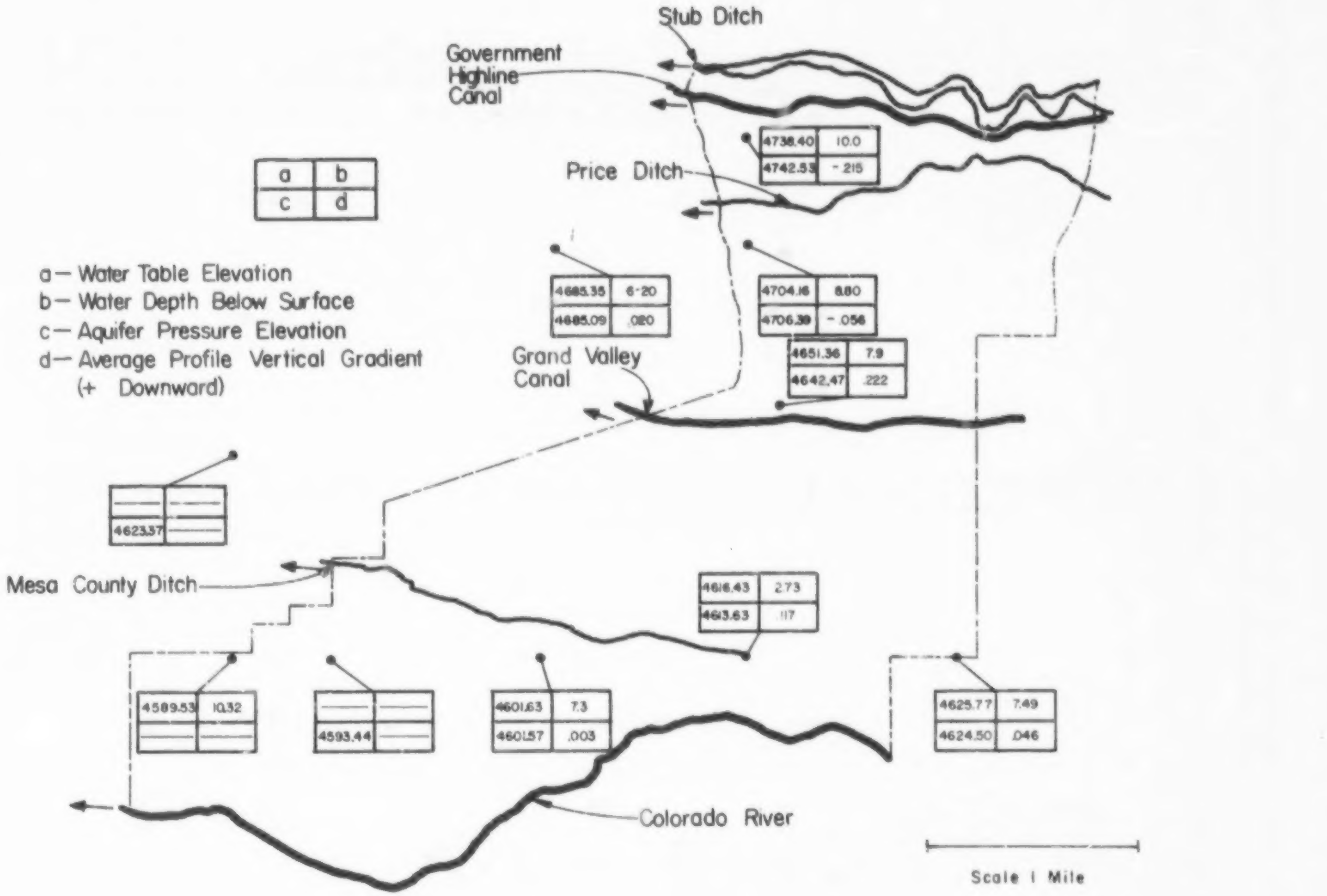

Stub Ditch
Government Highline Canal
Price Ditch
Grand Valley Canal
Mesa County Ditch
Colorado River
a
b
c
d
a— Water Table Elevation
b— Water Depth Below Surface
c— Aquifer Pressure Elevation
d— Average Profile Vertical Gradient (+ Downward)
4738.40
10.0
4742.53
-.215
4685.35
6-20
4685.09
.020
4704.16
8.80
4706.39
-.056
4651.36
7.9
4642.47
.222
4623.37
4616.43
2.73
4613.63
.117
4589.53
10.32
4593.44
4601.63
7.3
4601.57
.003
4625.77
7.49
4624.50
.046
Scale 1 Mile

Fig. 59. Water table elevations, depths below soil surface, average vertical gradients, and cobble pressure elevation for selected stations in the test area during July 1971.

Table 26. Results of hydraulic conductivity measurements from piezometers in Area I.

Location	Depth, ft.	K, in/hr.
D - 28.5	9	0.001
	14	0.013
D - 29	18	0.005
D - 30	10	0.005
	10	0.003
D - 31	10	0.025
	18	0.00375
D - 32	12	0.0118
	15	0.017
E - 29.5	15	0.017
	21	0.002
	35	0.001
E - 30	39	0.003
	42	0.002
E - 30.85	14	0.003
	21	0.002
	32	0.001
	42	0.0013
E - 31.5	14	0.007
	21	0.002
	39	0.062
E - 32.3	21	0.002
F - 30	37	0.0018
	45	0.011
F - 30.5	21	0.002
	35	0.017
	43	0.0006
F - 31	16	0.011
	23	0.025
F - 31.5	22	0.0006
	35	0.003
F - 32	47	0.013
	50	0.0025
	61	0.0007
FS - 30.5	15	0.0015
	21	0.001
	25	0.0035
FS - 31	14	0.0004
	21	0.003
	35	0.00035
	41	0.0032
FS - 32	14	0.0205
	29	0.0013

well, shown in Fig. 10, is quite similar to the logs of the 2-inch wells drilled in Area I, except that the cobble in Area I seemed to have a greater percentage of large rocks. In fact, this material is very similar to the boulders in the river channel, which can be observed during low flow periods. It would be the unqualified opinion of the writers that the cobble aquifer originated from river bottom deposits.

An examination of hydraulic pressures in the cobble during the same periods indicated for the piezometers reveals that a somewhat greater fluctuation with time occurs. During the spring period, the horizontal gradient in the area was 0.00983 ft/ft, while the gradient during the irrigation period was 0.0104 ft/ft. Thus, it is quite clear that the vast majority of subsurface return flows are taking place through the cobble aquifer.

Ground Water Management

The capability of controlling ground water flows has always been a necessary prerequisite in an irrigated area. The fact that the drainage in the Grand Valley is presently inadequate in the areas most affected near the river is unquestionable. But recently, the need for controlling irrigation return flows has become of primary concern from a salinity control standpoint to the valley.

In order to control the salt pickup from the Grand Valley the subsurface return flows through the cobble aquifer and the overlying soils must be reduced. It has been argued that even reducing ground water flows would not reduce the salt loadings because the reduced flow through the aquifer would simply become more concentrated and thus carry the same salt load. The results of this study indicate that ground water is retained in the soils and aquifer much longer than is necessary to reach chemical equilibrium with ambient salinity concentrations in the subsurface formations. Consequently, the writers feel that a reduction in deep percolation losses will result in a decreased salt loading reaching the Colorado River. However, whether a 50 percent reduction in moisture movement through the soil would result in a 50 percent reduction in salt pickup is not known at the present time.

The exact region of salt pickup through the soil profile and aquifer has not been sufficiently defined in this study. It was originally thought that when water came in contact with the Mancos Shale, the most significant load of salts was picked up. Since many of the soils seem to originate from the shale, the nature of the salt loading in the area is unclear. Studies should be undertaken to define the specific nature of water movement and associated chemical changes before the final assessment of salinity control alternatives is made. The results of such a study may possibly indicate that a field drainage system which intercepts the water before it percolates into the ground water basin may be a sound salinity control measure, since it would reduce the contact time of deep percolation and seepage losses in the soils.

SECTION XII

WATER AND SALT BUDGETS

Although seepage measurements before and after the linings were all that was necessary to determine the resulting seepage reduction, evaluation of the linings relative to the total system required accounting for the water and salt flows. In this manner, the relative magnitude of the segmented flow system could be evaluated and an indication of the importance of conveyance seepage flows could be given in relation to the other components of the irrigation and drainage network. This budgeting procedure has the potential for establishing the possibility of controlling salinity at other locations within the agricultural system.

The hydro-salinity flow system can be divided into an examination of the water and salt flows, even though the salt flow occurs within the water transport network. One completely independent part of the salinity system is the salt pick-up from soils and subsurface contacts.

This section will be presented and discussed in three parts:

(1) Review of water budget computations
(2) Review of salt budget computations
(3) Analysis of budgeting results

Water Budget Calculations

The computation of the water budgets is the first essential in hydro-salinity modeling because salt flows and water quality in general are dependent on the quantity and distribution of water in the hydrologic system. In all but the most limited cases, water budgeting requires some adjustment to formulated data in order to compensate for instrumentation limitations, data accuracy, and interaction among variables. As noted previously, a comparison of mass balance and direct calculation methods was made on ground water flows as a basis for model refinement. It seems justified to conclude that this procedure gives an additional degree of confidence to the results.

The first step in computing the budgets was to evaluate the distribution of the water before it reached the root zone. Water is initially diverted from the two rivers into the various canals from which a small percentage is lost by seepage, some is spilled into washes or drains in order to regulate capacity, and the bulk is diverted into the field lateral system. In the lateral network some of these flows are lost by seepage and the rest is applied to the cropland. In the Grand Valley irrigation system a large proportion of the field application eventually reaches the drainage system as field tailwater, and the final component enters the root zone for crop use.

Once in the root zone, opportunity exists for consumptive use by crops. Under optimum conditions, the water used from the root zone will approximate the crops' potential demand. Potential evapotranspiration from cropland surfaces in Grand Valley was computed using the modified Blaney-Criddle formulation. A summary of the calculations according to each canal system is shown in Table 27. These data were also derived for all potential water uses in the valley and have been tabulated in Table 28. The excess water in the root zone that cannot be retained in storage percolates through the soil profile until it reaches the ground water. Since the water table is not always at the bottom boundary of the root zone, a region of flow between this boundary and the water table should be considered. For purposes of this study, this region (soil profile) was initially assumed completely saturated and disregarded.

The ground water additions are comprised of canal and lateral seepage and deep percolation from excessive irrigation. Occasionally, the amount of precipitation is sufficient to account for some inflows to the ground water system. A proportion of ground water is either intercepted by the drainage system or transpired by phreatophytes. It was assumed here that phreatophytes use water at their potential rate and use all precipitation that falls on these acreages. Because of the fluctuating nature of the ground water additions, the storage within the ground water basin also varies significantly throughout the year. In budget computations, a negative storage change indicates that more flows are leaving the subsurface basin than are entering. The remaining water is forced to flow towards the river by the hydraulic gradients acting on the water from elevation differences in the local topography. These flows were referred to in the model as the total ground water outflows and were then used to evaluate the performance of the entire model.

Salt Budget Calculations

Although the salinity flow system generally follows the water flows, there are three additional complicating factors that

Table 27. Potential cropland demand in the Grand Valley by canal system serving the land. (units in acre-feet)

Canal System	Month						
	Apr	May	Jun	Jul	Aug	Sep	Oct
Stub Ditch	70	160	320	350	250	160	90
Government Highline Canal	1,800	5,230	13,130	14,580	11,000	6,970	8.380
Price Ditch	480	1,160	2,380	2,560	1,850	1,190	670
Grand Valley Canal	2,120	5,840	14,040	14,980	11,440	7,090	6,230
Mesa County Ditch	120	290	610	660	480	300	180
Adjacent to River	30	70	180	200	140	90	50
Orchard Mesa #1	480	1,170	2,470	2,800	2,060	1,330	780
Orchard Mesa #2	420	960	1,780	2,010	1,390	900	510
Redlands	340	780	1,450	1,710	1,220	790	210
Total	5,860	15,660	36,360	39,850	29,830	18,820	17,100

Table 28. Potential evapotranspiration demand of the Grand Valley. (units in acre-feet)

Water Use	Month						
	Apr	May	Jun	Jul	Aug	Sep	Oct
Irrigated Cropland	5,860	15,660	36,360	39,850	29,830	18,820	17,100
Domestic* Use	1,410	3,020	5,050	6,010	4,360	3,000	1,640
Evaporation	640	1,320	2,190	2,610	1,900	1,360	820
Phreatophyte Consumption	4,330	9,430	18,610	25,100	19,910	14,540	7,920
Total	18,240	29,430	62,210	73,570	56,000	37,720	27,480

*Assumed 65% consumed.

must be considered. The first of these is the ion exchange process that occurs in the root zone. Because the scope of this project did not allow for such an extensive examination, this factor was ignored. It should be emphasized that this information is very important to understanding salinity problems in agricultural areas.

The second aspect that must be considered is the quantity of salts actually imparted to the water from the soils themselves. The distribution of this "pick up" quantity is not known and was assumed to occur only in the ground water basin. This conclusion is obviously false, but does not interfere with the scope of this modeling effort. Again, the knowledge of where the salt is being added is of the utmost importance to salinity control planning. For example, if it were known that little salt is actually added in the root zone, then the interception of deep percolation by a system of field tile drainage would be a feasible salinity control alternative.

The third and final component of the independent variables affecting salt movements is related to the salt and water storage changes that occur within the ground water basin. When a large influx of water is added via deep percolation or conveyance seepage, this water has not as yet picked up much salt due to the short time it has been in contact with the soils. As a result, the large storage increases in the spring and early summer result in only small salt flow to the ground water basin. On the other hand, when large storage decreases occur in the late fall and early winter, a relatively large salt depletion occurs from the system. These negative storage changes were found from water quality data to be on the order of 2-3 times the salt movement as compared with the positive ground water storage changes. This particular parameter regarding the salinity flow was handled in the salinity phase of the model.

Water and Salt Budgets

The water and salt budget summaries recorded in this section represent both the pre-construction evaluation (1969 water year) and the post-construction study (1971 water year). Data collection and supplementary studies were continued during the interim 1970 water year, but formal budgeting was not calculated.

Numerous considerations such as improved experience, more comprehensive testing, and better project facilities, combined during the course of this investigation to modify certain conclusions. In addition, a clearer understanding of the overall valley hydro-salinity mechanism was gained, so a better basis for suggesting salinity management alternatives can be presented. The results of these general improvements were several changes in the water and salt budget items that will be explained in the following pages.

Because of the large page requirements for a typical water or salt budget, the presentation herein has been partitioned into the flow system before and after distribution within the root zone. Certain computational steps have been omitted from the results and, if the reader has difficulty following the data breakdown, it is suggested that Section VI be reviewed.

Water and Salt Inflow Distribution in Area I.

The first part of the water and salt budgets has been included for the 1969 and 1971 water years in Tables 29, 30, 31, and 32. Although a significant year-to-year variation in the magnitude of water and salt flows is expected, several changes have occurred as noted previously from better experimental evidence. Notable among these modifications are the increase in average area farm efficiency resulting from an improved farm efficiency study, a large increase in the magnitude of lateral seepage losses as a result of closer examination of these flows, and somewhat different values of ground water changes and salt flows that have resulted from more extensive data. For example, the water quality data used in preparing the 1969 budget were taken from only a few field measurements and tend to be higher than the 1971 data, which more closely paralleled the data on the river stations.

Ground Water and Salt Flows

Water and salt movements beneath the soil surface include evapotranspiration and drainage return flows, tabulated in Tables 33, 34, 35, and 36. These data also reflect some model improvements that were made, particularly in the salt flow system and the ground water model. For example, the 1969 budgets are based upon a ground water model consisting of three strata, whereas the 1971 model was limited to two because the flows in the tighter clay strata can be neglected. In addition, the salinity segment of the model was modified to compensate for the discrepancies found in the salt flows associated with storage change in the ground water basin as discussed; and the salt pickup and ground water salt storage changes have been separated for the 1971 budgets to allow for clearer understanding of the budgets.

Table 29. Water budget inflows to Area I during 1969 study period. (all units in acre-feet)

	PRECIPITATION		CANAL DIVERSIONS			LATERAL DIVERSIONS		
Month	cropland	phreat.	seepage	spillage	lateral diversions	seepage	tailwater	root zone diversions
OCT	200	40	120	1200	2050	80	1200	770
NOV	130	30	0	0	0	0	0	0
DEC	130	30	0	0	0	0	0	0
JAN	130	30	0	0	0	0	0	0
FEB	180	40	0	0	0	0	0	0
MAR	180	40	0	0	0	0	0	0
APR	180	40	120	2000	2920	120	980	1820
MAY	130	40	120	2000	3900	120	1600	2180
JUN	130	40	120	2000	4510	120	1600	2790
JUL	130	40	120	2000	4800	120	1600	3080
AUG	240	50	120	2000	4410	120	1500	2790
SEP	200	40	120	2000	3220	120	1500	1600
ANNUAL	1960	460	840	13200	25810	800	9980	15030

Table 30. Water budget inflows to Area I during 1971 water year.
(all units in acre-feet)

	PRECIPITATION		CANAL DIVERSIONS			LATERAL DIVERSIONS		
Month	cropland	phreat.	seepage	spillage	lateral diversions	seepage	tailwater	root zone diversions
OCT	420	130	30	1200	2600	270	1350	980
NOV	120	40	0	0	0	0	0	0
DEC	100	30	0	0	0	0	0	0
JAN	140	40	0	0	0	0	0	0
FEB	10	10	0	0	0	0	0	0
MAR	470	150	0	0	0	0	0	0
APR	200	70	30	2000	2800	260	860	1680
MAY	0	0	30	2000	3960	370	1220	2370
JUN	240	80	30	2000	4460	420	1370	2670
JUL	160	50	30	2000	4830	460	1460	2910
AUG	120	40	30	2000	4070	380	1400	2290
SEP	210	70	30	2000	3230	290	1350	1620
ANNUAL	2190	710	210	13200	25980	2450	9010	14520

Table 31. Salt budget inflows to Area I, in tons of total dissolved solids, during the 1969 water year.

	Canal salt diversions			Lateral salt diversions		
MO	seepage	spillage	lat. div.	seepage	tailwater	root zone diversions
OCT	110	1890	1950	70	1140	740
NOV	0	0	0	0	0	0
DEC	0	0	0	0	0	0
JAN	0	0	0	0	0	0
FEB	0	0	0	0	0	0
MAR	0	0	0	0	0	0
APR	160	2720	4000	160	1340	2500
MAY	160	2720	5300	160	2170	2970
JUN	160	2720	6130	160	2180	3790
JUL	110	1900	4570	110	1530	2930
AUG	110	1900	4200	110	1440	2650
SEP	110	1900	3070	110	1440	1520
ANN.	920	15750	29220	880	11240	17100

Table 32. Salt budget inflows to Area I, in tons of total dissolved solids, during the 1971 water year.

	Canal salt diversions			Lateral salt diversions		
MO	seepage	spillage	lat. div.	seepage	tailwater	root zone diversions
OCT	30	1890	2540	260	1280	1000
NOV	0	0	0	0	0	0
DEC	0	0	0	0	0	0
JAN	0	0	0	0	0	0
FEB	0	0	0	0	0	0
MAR	0	0	0	0	0	0
APR	10	2720	1520	140	460	920
MAY	20	2720	2690	250	820	1620
JUN	20	2720	3640	340	1110	2190
JUL	30	1900	4600	440	1390	2770
AUG	30	1900	4430	410	1520	2500
SEP	30	1900	3080	280	1280	1520
ANN.	170	15750	22500	2120	7860	12520

Table 33. Water budget ground water flows in Area I during the 1969 study period. (all units in acre-feet)

MO	Root Zone Diversions cropland use	 deep perc.	Ground Water Flows drainage flows	 phreat. use	 storage change	 subsur. outflow
OCT	460	510	200	200	-100	450
NOV	130	0	180	40	-560	370
DEC	70	60	150	30	-400	310
JAN	0	130	120	30	-300	310
FEB	0	180	70	40	-200	310
MAR	0	180	60	40	-200	320
APR	680	1320	300	300	600	400
MAY	920	1390	300	310	540	520
JUN	1670	1250	300	330	300	600
JUL	2000	1210	300	350	200	640
AUG	1820	1210	250	400	200	650
SEP	1140	660	500	280	-100	560
ANN.	8890	8100	2430	2350	- 20	5440

Table 34. Water budget ground water flows in Area I during 1971 study period. (all units in acre-feet)

	Root Zone Diversions		Ground Water Flows			
MO	cropland use	deep perc.	drainage flows	phreat. use*	storage change	subsur. outflow
OCT	490	510	290	300	100	520
NOV	50	70	240	70	-700	460
DEC	0	100	180	0	-450	370
JAN	0	140	150	0	-350	340
FEB	20	0	90	10	-450	350
MAR	130	330	100	80	-250	400
APR	310	1570	140	280	1000	440
MAY	760	1610	190	460	800	560
JUN	1620	1290	240	590	300	610
JUL	1780	1290	260	700	150	670
AUG	1330	1080	310	470	0	710
SEP	860	970	300	330	0	660
ANN.	7350	9360	2490	3290	150	6090

*adjusted for precipitation

Table 35. Ground water salt flows in Area I, in tons of total dissolved solids, during the 1969 water year.

	Root Zone Salt Budget			Ground Water Salt Budget				
MO	salt depository	accumulated storage	salt add. to G.W.	total salt added	pickup	drainage salt	salt storage change	salt outflow
OCT	630	0	740	920	0	1360	- 820	3670
NOV	190	190*	0	0	4970	1270	-5610	3700
DEC	120	0	310	310	3690	1210	-3600	2790
JAN	40	0	40	40	3810	1060	-2700	2790
FEB	50	0	50	50	3640	670	-1950	3020
MAR	50	0	50	50	3880	580	-2090	3350
APR	1330	0	2500	2820	4230	2650	2000*	4400
MAY	1670	0	2970	3290	4110	2450	2000*	4950
JUN	2720	0	3790	4110	3430	2240	2650*	5300
JUL	2240	0	2930	3150	3110	2040	1630*	4220
AUG	2110	0	2650	2870	4050	1700	1630*	5220
SEP	1350	0	1520	1740	4190	1360	- 810	4570
ANN.	12500	190	17550	19350	47220	18590	-7670	47980

*storage change from irrigation, not ground water outflow

Table 36. Ground water salt flows in Area I, in tons of total dissolved solids, during the 1971 water year.

	Root Zone Salt Budget			Ground Water Salt Budget				
MO	salt depository	accumulated storage	salt add. to G.W.	total salt added	pickup	drainage salt	salt storage change	salt outflow
OCT	470	0	1000	1290	6000	1970	1000	4220
NOV	0	0	0	0	0	1960	-6760	4800
DEC	0	0	0	0	0	1470	-4400	2930
JAN	0	0	0	0	0	1180	-3470	2290
FEB	0	0	0	0	0	690	-4520	3830
MAR	0	0	0	0	0	770	-2550	1780
APR	170	0	920	1070	4970	920	1540	3580
MAY	510	0	1620	1890	5750	1260	1540	4840
JUN	1320	0	2190	2550	5760	1600	1240	5470
JUL	1690	0	2770	3240	5780	1770	1140	6110
AUG	1440	0	2500	2940	6440	2100	0	7280
SEP	820	0	1520	1830	6420	2040	0	6210
ANN.	6420	0	12520	14810	41120	17730	-15140	53340

Analysis of Results

Examination of the data presented in Tables 29 through 36 indicates some interesting results. An evaluation of the 1971 budgets will be made herein since they reflect the changes in the system due to the linings, although the same procedure could easily be applied to the 1969 budget.

The first important consideration is the distribution of the water from the canal to the drain or subsurface returns to the river. Based upon the seepage measurements before and after the linings, a reduction from 840 to 210 acre-feet per year (75% reduction) canal seepage was determined. On a valley wide scale, the lining of canals could be expected to reduce seepage losses from the present 5% to about 1% of the total canal diversions. The seepage losses from the lateral system could be expected to be much greater, probably from 10% to about 2% of the total agricultural diversions. It should be noted at this point that the data tabulated under "spillage" is superfluous, since these flows were not measured and are included only to make the seepage losses representative.

The distribution of the water diverted into the lateral system show that 10% is seepage, 35% is field tailwater and 55% is actually supplied to the root zone. However, only 33% of the total lateral diversion is actually used by the crops, thus making the area farm efficiency equal to 40% if a 7% leaching requirement is imposed.

In the Grand Valley it is useful to examine the ground water flows and the drainage flows together. Of the total 9,360 acre-feet entering the ground water basin, 2,490 acre-feet, or 27%, is intercepted and carried away by the drainage system. Phreatophytes consume about 35% of these flows, and the remaining 38% returns to the river through the subsurface aquifer. Thus, of the water carried by the drainage system (11,500 acre-feet), only 22% is drainage return flows and 78% is field tailwater.

Even though an examination of the respective water flows yields useful information for improving water management practices, the most important considerations to this study deal with the salinity flow network. From Tables 32 and 36 it can be seen that the total inflowing salt amounted to 22,670 tons (excluding spillage as it is assumed to have no influence on the budgets), but the total salt outflows amounted to 78,930 tons, thereby indicating a net gain of 56,260 tons, or 12 tons per acre. This would suggest that Area I contributes somewhat more per acre than the valley as a whole and indicates the probability that certain areas contribute more than others. Thus, a feasible salinity control alternative must surely consider the delineation of these areas.

Of the total salt input in Area I, 14,810 tons (0.86 tons/acre-foot) was computed to be the area contribution to the ground water system, with 12,520 tons resulting from over-irrigation (deep percolation), 170 tons from canal seepage, and 2120 tons from lateral seepage. Thus, for each ton of salt added to the ground water basin (assuming that all salt pick up occurs here), 3.8 tons can be expected to result in the irrigation return flows. The effects of the canal and lateral linings which reduce water inflows to the subsurface aquifers by 930 acre-feet annually would reduce the salt contribution to the Colorado River by 4700 tons.

In terms of extending this conclusion to the valley as a whole, it is probably premature at this point because insufficient research has been conducted to quantify the expected salinity reductions resulting from large scale projects. For example, if the amount of water reaching the ground water was decreased by, say, 50%, the question needing study is whether the corresponding salt decrease would be 50% or, say, only 30%.

SECTION XIII

SALINITY MANAGEMENT ALTERNATIVES

The saline soil conditions associated with inadequate drainage and the basin-wide urgency of rising salinity concentrations make water management in the Grand Valley increasingly important. The inefficiencies apparent in present practices of water use result from a combination of abundant water supply, low water costs, and critical soil and topographic characteristics. These problems would have been dealt with more substantially long ago if the economic penalties had been more severe. In the Grand Valley, the 30% of the acreage highly affected by poor water management was an insufficient deterrent to offset the belief that use must be made of all water rights in order to protect them. Nevertheless, the time has approached when the growing salinity problem in the Colorado River Basin, complicated by recent and planned development in the Upper Basin States, has forced areas like the Grand Valley to plan for more efficient management of water. This study has been the first attempt to delineate the available alternatives. Although it has been primarily directed toward the investigation of the effects of reducing conveyance seepage losses, it has provided an insight into the probable effects of other types of salinity control measures.

The stated objectives of this project could not have been realized without an extensive evaluation of all the interrelated factors of the salinity problem. As a result of this experience, the feasibility of lining canals and laterals to reduce seepage into saline ground water flows could be determined, but a great deal of supporting generalized comment is possible concerning the potential of other management schemes.

During the course of the research effort discussed herein, the need for further research became quite evident. In addition, the possibility of certain alternatives seemed constrained because of either the inadequacy or complete limitations of water use institutions and legislation. This discussion can be divided into three parts:

(1) Water management improvements necessary in the existing system as a prerequisite to reducing the salinity problem resulting from irrigation practices in the Grand Valley;

(2) Research needs associated with implementing salinity control measures; and

(3) Institutional requirements for salinity control in irrigated agricultural areas.

Water Management Improvements

The Water Quality Act of 1965 amended the Federal Water Pollution Control Act to require that water quality standards be established for all interstate waters in the nation including the Colorado River. The states were given first opportunity to establish standards, which were then subject to federal approval. The standards consist of stream classification specifying beneficial water uses to be protected, water quality criteria which specify limits on various parameters, and an implementation plan for necessary pollution abatement measures to meet established criteria. The Colorado River Basin states jointly developed guidelines for establishing standards for all interstate streams in the basin to insure compatibility of standards between states. An important agreement reached by the states was that no numerical salinity criteria would be established until such time that available information on salinity control measures was adequate to form the basis for establishing equitable, workable and enforceable salinity standards. The various states subsequently established water quality standards which did not include numerical salinity criteria. The standards received federal approval with the provision that numerical salinity criteria would be established by the states as soon as adequate information was developed by research and technical investigations planned or underway.

The delay in setting salinity criteria has provided the opportunity for comprehensive study and planning of salinity control measures, such as this project. The basic salinity control technology is rapidly being developed so that the establishment of salinity standards at key points in the system will be necessary in the relatively near future. The Grand Valley Water Purification Project, Inc., interested citizens, and state legislators have realized the need to promote investigations that will lead to a feasible salinity control program for the valley. This attitude is extremely farsighted and will prove beneficial to the irrigators in the area by studying all available solutions and providing for increased farm output to offset the costs that will be incurred. However, the authors feel impelled to state their opinions concerning the emphasis that should be followed, based upon the experience gained from participation in this project. The internal phases of a salinity control program in the valley involve canal system management, on-farm water use improvement, and drainage.

Canal System Management

Although the primary use of water is on the farm, the primary control is not. Therefore, the first step in effecting a sound management scheme is the incorporation of more rigid water company controls. It has been alluded to several times in the preceding sections that the adjudicated water supply under normal water years is especially abundant, on the order of 8-9 acre-feet per irrigated acre. With such a high water duty, waste and inefficient use are encouraged. There are several conditions existing that should be improved. These include the increased control of canal diversions to reduce spillage into natural washes and drains, company control of lateral turnouts to avoid the excessive waste below in the form of dumping water into the drainage system when not used in multiple use systems, and control on the delivery mechanism such as a call period to efficiently meet irrigation demands. In summary, for irrigation to continue at the present or greater levels, while taking into account salinity control, several new directions must be taken:

(1) Efforts to accomplish as much system (canal and lateral) rehabilitation as possible, which would imply an extensive lining program to reduce maintenance and facilitate operations;

(2) The first and foremost requirement of efficient water management anywhere is sound water measurement with acceptable devices being installed at each lateral turnout and at major junctions within the lateral system, which requires that some company control be involved below the turnout; and

(3) An organized and equitable system of call periods should be implemented to facilitate tighter canal discharge control.

None of these suggestions could or should be imposed too rapidly, since such a scheme would constrain to a large degree an already burdened way of life. However, a well coordinated plan for a gradual transition should be made. This, of course, means two things. First, a significant portion of some water rights would be left in the river subject to abandonment. Consequently, until the social, political, and economic objectives of the State of Colorado become clearly defined, it should be required that the right to use these excesses be left in the Grand Valley. The great need is obviously in examining the institutional framework of western water laws to change interpretations so provisions are made for incentives for more efficient water use. Numerous questions need to be resolved in this subject area before wise and equitable decisions can be made. It should be re-emphasized that the study of feasibility and mechanisms of various institutional changes could be effectively incorporated into the objectives of an extended Grand Valley Water Purification Project.

The second aspect of management improvements involves the increasedrequirement of company personnel, equipment, and operation expenditures which would force an increase in the price of water to irrigators. External financial sources such as Federal grants and revenues for renting excess water would help, but the subtle advantages of expensive irrigation water as a salinity control technique are many. Most irrigators would be more reluctant to be wasteful if farm profits were significantly diminished as more and more water was not effectively used.

Historical records clearly indicate the potential salinity control of efficient water management during water short years. Therefore, it seems well justified to conclude that although a well coordinated plan of attack between company management, drainage, and improvements to on-farm water use is required, the most important and most urgently needed feature is improvements to canal company operation. Without detailed consideration of all relevant parameters, a great deal of resource could be wasted. Thus, there is a great need to investigate further the legal, social, and engineering factors influencing the optimal method of canal company management.

On-Farm Water Management

Excessive application of water to soils in the Grand Valley is undoubtedly the primary cause of salt inputs to the river system. Increased irrigation efficiencies will be the most influential factor affecting improvements in salt contribution, drainage problems, and crop production. It is estimated that the valley-wide farm efficiency ranges between 30 to 40%. In this range of operation, every acre-foot of water consumptively used by crops must be accompanied by about two and one-half acre-feet that flows as deep percolation or field tailwater. If improved canal management measures were present, farm efficiency would be sharply enhanced. The real need in this area is a program to demonstrate improved irrigation methods and to convince irrigators of the benefits. Improvement to farm efficiency may be achieved by the following approaches:

(1) Demonstration that higher water use efficiencies can result in higher crop production and lower fertilizer costs.

The most effective format is probably similar to this project, which could also incorporate some of the research gaps in present technology, such as the development of prediction techniques for subsurface return flows, including associated chemical changes in the moisture movement through the soil profile.

(2) Incorporation of an irrigation scheduling study into a demonstration project, where the emphasis includes water quality. This study could eventually be expanded to a valley program. This information would aid the irrigator in determining when and how much water to apply. This program has been initiated in other areas, but not as a salinity control method.

(3) Lateral system rehabilitation must be considered as a part of any improved farm management scheme because of the complexity of the present system. Some lateral turnouts serve over 100 users and thus a real need exists for linings, division structures, and measurement devices in order to insure an equitable distribution.

The process of improving on-farm water use will be difficult to achieve. The need, however, is apparent. With the need for salinity control being so important, the necessity of a correlated effort from all factions in the valley is amply demonstrated.

Drainage

The present open ditch drainage system is largely ineffective in reducing the high water tables and, for the most part, is used mainly as a conveyance for field tailwater. The possibility that these drains actually contribute to the ground water in the test area was found non-existent, but they may at other localities throughout the valley. In any event, the reason for the general inadequacy of these drains is based on the fact that insufficient attention appears to have been given to the true characteristics of the problem. Piezometric readings and stratum surveys taken throughout the valley indicate that a relatively impermeable layer confines a cobble aquifer commonly producing a vertical gradient. The confining layer has been found to be discontinuous in at least one spot, allowing water to move more freely into and out of the cobble, thus increasing the drainage potential. Measurements of hydraulic conductivity and hydraulic gradients show conclusively that most flows into the river, occurring as subsurface flows, are transmitted by the cobble aquifer. Since the distribution of the salt pickup through the soil profile, or the variation in salt pickup throughout the valley, is not known, the type and extent of drainage may be very important to future salinity control proposals.

It can be realized that area drainage should be a combination of interceptor drains to collect ground water flows from higher lands, pump drainage to relieve vertical gradients and lower water tables in selected areas, and field tile-type drainage to control the fluctuations of the moisture levels in the root zone. These are known to be important principles in successful farming operations. Because the expense of field drainage is high and the bulk of the costs probably fall on the land owner, further effort is needed to find an acceptable drainage technique.

An improved drainage system without an accompanying increase in on-farm water use efficiency and improved operation of canals would only magnify the already critical problem. Obviously, if the water tables are lowered, more water can and will be applied, irrigated acreages will increase into the reclaimed areas, and salt loadings would probably rise. However, if effective drainage accompanies improved water management practices in general, the productivity of local agriculture will be greatly increased as the salt problem is alleviated.

Future Research Requirements

There are two basic requirements for further research in the Grand Valley. The first is concerned with further technological development. The second is related to demonstrating to local irrigation officials and irrigators both the importance and feasibility of alternate salinity control methods.

Needed Research in Filling Existing Technological Gaps

The empirical nature of certain assumptions made as part of this modeling effort has been pointed out. First, the distribution of the salt actually contributed from the soil and aquifer is not known. If, for example, most of the salts are added in the ground water flows, then field drainage which intercepts the deep percolation losses before they come in contact with these deeper strata becomes an effective salinity control technique. In addition, it is not unreasonable to assume that different areas with their different soil characteristics, cropping patterns, and water-use practices yield different salt loads. Thus, one of the most pressing technological needs is the development of prediction techniques for describing the quantity and quality aspects of subsurface return flows. Models of this type should incorporate sufficient sophistication to predict ionic exchange and other characteristics of water and salt flows in soils. The necessity of models of this format is amply demonstrated by the need to predict in acceptable detail the effects of various salinity control programs.

Because any salinity control practice would hopefully improve the local agricultural conditions, the knowledge of the basic parameters surrounding irrigation scheduling should be investigated. For example, it is known that certain growth periods during the season are critical to optimizing production. Research should be conducted to test the correlated effects of water application, soil salt concentrations, and the relative preponderance of the various cations on crop yields. Specifically, the salinity control aspects of irrigation scheduling should be given attention, since this point of view has not been taken previously.

Need for Demonstrative Research

The success of water quality improvement programs without extensive public and private support has always been highly questionable. Salinity management in the Grand Valley will be no exception. There are at least two major needs remaining for demonstration in the Grand Valley. They are improved on-farm water management through irrigation scheduling and field drainage. Actually, field drainage would probably be best suited if the largest proportion of salts were being picked up below the root zone. Individual demonstration projects similar to this particular one serve to evaluate some of the gaps in basic knowledge and to solicit local cooperation. Much of the important basic research should be accomplished before actual regional salinity management is undertaken on a large scale, in order to facilitate a careful planning schedule. Consequently, demonstration projects planned for the future should involve some coordination among all three types of programs in order to demonstrate successfully the absolute requirement for coordination between salinity control programs. It should be noted once again that implementation of salinity management methods, without considerable planning based on sound experimental evidence and local conviction, may be very ineffective in the long run.

Institutional Requirements for Salinity Control

When all aspects are considered, the institutional constraints compromising the wishes of local water users and regional salinity planners will be the most difficult and the most important to resolve. Salinity control in the Grand Valley simplifies immediately to the restricted use of water resulting in a quantity that need not be diverted. The question immediately confronted is what happens and who obtains the water saved by salinity control programs in the Grand Valley. The legal constraint here is the possibility of forced abandonment of some of the decreed water right in the valley and then the successive reapportionment to other uses. Thus, the water use must be changed from irrigation to another desired use if it is to be left in the valley supply.

Ineffective drainage, excessive salt inputs to the Colorado River, and marginal agricultural production from at least 30% of the valley are not three independent problems, just one - poor water management practices by an irrigated agriculture. Grand Valley is not unique in this respect either. Consequently, a step parallel to conducting research on feasible solutions is the implementation of salinity control measures, which will require the formation of an administrative body to coordinate the activities of the various entities concerned with irrigation in the valley. These and similar questions lead the writers to suggest a valley authority for coordinating the salinity control program. The basic structure of this institution would allow it to seek salinity control funding, research funding, etc., and to transmit pertinent data and planning efforts between the federal-state entities and the local organizations. It would also stimulate the interest and investigation of economic, social, and legal problems influential in salinity reductions.

Miller's (21) conclusion that the scope and severity of the drainage problem in 1916 required a complete community organization dedicated to the problem led to the formation of the Grand Junction Drainage District. The prospect of obtaining federal money for canal and lateral lining as a first step in salinity control in the late 1960's led to the organization of the Grand Valley Water Purification Project, Inc. The next step is a logical extension of the GVWPP into a regional salinity management coordinating council. Since the present organization of GVWPP is comprised of local irrigation and drainage officials, it seems justified to broaden the format to include such responsibilities.

The possibility of organizational consolidation at the local level among the existing irrigation companies to facilitate more efficient irrigation operations as well as to operate the valley salinity control program should also be considered. Such a consolidation would allow a pooling of personnel, equipment, and finances, thereby providing some savings in operational costs, but more importantly, allowing the entire Grand Valley irrigation enterprise to be operated as a truly integrated system.

SECTION XIV

ACKNOWLEDGMENTS

The authors have become indebted to many individuals during the course of this study. Especially rewarding have been the associations with Mr. George Bargsten, Mrs. Barbara Mancuso, Mr. Ted Hall, Mr. Jim Taylor, and Mr. Orlando Howe for their tireless efforts to conduct this research successfully in the Grand Valley.

Others who have contributed greatly to the results of this work on different occasions include Miss Diane Peterson, Mr. Robert Evans, Mr. Thomas Huntzinger, Mr. Van Steven Higinbotham, Mr. Ray Bennett, and Mr. Hugh Barrett, most of whom have also been students of the senior author.

The cooperation extended on numerous occasions by the officials of the Grand Valley Water Purification Project, Inc., has been greatly appreciated throughout the period of study.

The writers would also like to thank Miss Kevin Feigen for typing the final drafts of this manuscript.

The work from which this report is derived was supported by funds provided by the U.S. Environmental Protection Agency, Water Quality Office, Demonstration Project 13030 DOA. Especially appreciated has been the support of the Project Officers, Mr. L. Russell Freeman (FY69), Mr. James R. Vincent (FY70-71), and Dr. James P. Law, Jr., since July 1, 1971. In addition, the constructive criticisms offered by Mr. C. E. Veirs of EPA throughout the course of this investigation have been very helpful.

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*U.S. GOVERNMENT PRINTING OFFICE:1972 514-148/69 1-3